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N73-30033
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FULL-SCALE WIND-TUNNEL INVESTIGATION OF EFFECTS OF SLOT SPOILERS ON THE AERODYNAMIC CHARACTERISTICS OF A LIGHT TWIN-ENGINE AIRPLANE

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • SEPTEMBER 1973

1. Report No. NASA TN D-7315	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle FULL-SCALE WIND-TUNNEL INVESTIGATION OF EFFECTS OF SLOT SPOILERS ON THE AERODYNAMIC CHARACTERISTICS OF A LIGHT TWIN-ENGINE AIRPLANE		5. Report Date September 1973
		6. Performing Organization Code
7. Author(s) Harry A. Verstynen, Jr., and Dominick Andrisani II		8. Performing Organization Report No. L-8865
		10. Work Unit No. 760-60-01-00
9. Performing Organization Name and Address NASA Langley Research Center Hampton, Va. 23665		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Note
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A wind-tunnel investigation has been conducted to determine the effects of slot spoilers on the longitudinal and lateral aerodynamic characteristics of a full-scale mockup of a light twin-engine airplane. The slots were located along the leading edge of the flaps and were used to modulate the flap-induced lift as a possible means of achieving direct lift control. The data showed that the slots were effective in spoiling up to 61 percent of the flap-induced lift, but that an adverse pitching-moment change (nose up) accompanied opening the slots. Opening the slots was found to decrease slightly the downwash angle at the tail and to increase slightly the longitudinal stability of the model.

17. Key Words (Suggested by Author(s)) Direct lift control devices; Spoilers; Slot spoilers	18. Distribution Statement Unclassified – Unlimited

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 34	22. Price* Domestic, $3.00 Foreign, $5.50

*For sale by the National Technical Information Service, Springfield, Virginia 22151

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SUMMARY

A wind-tunnel investigation has been conducted to determine the effects of slot spoilers on the longitudinal and lateral aerodynamic characteristics of a full-scale mockup of a light twin-engine airplane. The slots were 5.08 cm (2.0 in.) wide, covered 82 percent of the flap span of the model, and were located just aft of the leading edge of the flap. The slots were used to modulate flap-induced lift as a possible means of direct lift control.

The data showed that opening the slots decreased the lift coefficient, decreased the drag coefficient, and increased the pitching-moment coefficient (nose up). The maximum effectiveness of the slots, which was at angles of attack of 6° to 8°, resulted in a decrease in lift coefficient of about 0.32, or approximately 62 percent of the flap-induced lift. Opening the slots had a slight stabilizing effect on the longitudinal stability of the model and no effect on the lateral stability. As might be expected for a reduction in lift, opening the slots decreased the average downwash angle at the tail. The data also showed that the rolling moment created by a fully asymmetric slot condition is about one-half the roll-control power available on the basic model.

INTRODUCTION

The concept of direct lift control has been investigated as a means of increasing pilot tracking performance on the glide slope, reducing pilot workload during IFR approaches, and decreasing touchdown dispersions. Most of the techniques proposed for achieving direct lift control, however, require the rapid movement of aerodynamic surfaces, such as flaps or spoilers, which have large aerodynamic hinge moments and thus require large actuation forces and complex actuating mechanisms.

A technique for achieving direct lift control with very small actuating forces and simple mechanisms has been proposed (ref. 1). In this technique, the lift increment produced by flap deflection can be modulated by opening or closing spanwise slots, known as

slot spoilers, located along the leading edge of the flap. Previous wind-tunnel investigations have been conducted of slot-spoiler-equipped wing-body models, and the results are reported in references 1 and 2. The present report covers a full-scale wind-tunnel investigation of slot spoilers fitted on a full-scale mockup of a twin-engine general aviation airplane. Basic aerodynamic data for this configuration without slot spoilers are reported in reference 3. The present results are for an angle-of-attack range from -4° to 20° and an angle-of-sideslip range of $\pm 8^{\circ}$. The test Reynolds number based on a mean aerodynamic chord of 1.53 m (5.0 ft) was 2.96×10^{6} for thrust coefficients of 0.0 and 0.20, and was 2.39×10^{6} for a thrust coefficient of 0.44. Stick-fixed and stick-free longitudinal characteristics, lateral characteristics, and downwash effects of slot spoilers were investigated.

SYMBOLS

Figure 1 shows the stability-axis system used in the presentation of the data and the positive directions of forces, moments, and angles. The data are computed about the moment center shown in figure 2, which is at longitudinal station 85, or 10.0 percent of the mean aerodynamic chord, and 0.30 m (1.0 ft) below the fuselage reference line.

Measurements and calculations were made in the U.S. Customary Units. They are presented herein in the International System of Units (SI) followed by the U.S. Customary Units in parentheses.

b — wing span, 10.97 m (35.98 ft)

C_D — drag coefficient, $\frac{\text{Drag}}{qS}$

C_L — lift coefficient, $\frac{\text{Lift}}{qS}$

C_l — rolling-moment coefficient

C_m — pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$

C_n — yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$

C_Y — side-force coefficient, $\frac{\text{Side force}}{qS}$

C_{l_β} — lateral stability parameter

C_{n_β} — directional stability parameter

C_{Y_β} lateral stability parameter

$-\frac{dC_m}{dC_L}$ longitudinal stability parameter

$\bar{c}$ mean aerodynamic chord (m.a.c.), 1.53 m (5.0 ft)

q free-stream dynamic pressure, N/m^2 (lb/ft^2)

S wing area, 16.5 m^2 (178 ft^2)

T effective thrust (at $\alpha = 0^o$), Drag (propellers removed) minus Drag (propellers operating)

T_c' thrust coefficient, $\frac{T}{qS}$

X_s longitudinal axis

α angle of attack of fuselage reference line, deg

β angle of sideslip, positive when nose is to left, deg

δ_a total aileron deflection, positive right aileron down, $(\delta_a)_{left} - (\delta_a)_{right}$, deg

δ_f flap deflection, positive trailing edge down, deg

δ_s slot width, percent of mean aerodynamic chord

ϵ downwash angle at tail, deg

ΔC_D change in drag coefficient

ΔC_L change in lift coefficient

$(\Delta C_L)_{flap}$ change in lift coefficient due to flap deflection

$(\Delta C_L)_{slot}$ change in lift coefficient due to slot opening

ΔC_m change in pitching-moment coefficient

MODEL

The model tested was a light, twin-engine, low-wing monoplane. The principal dimensions of the model are given in figure 2, and a photograph of the model mounted in the tunnel test section is presented as figure 3. The model had a wing span of 10.97 m (35.98 ft). The wing area of 16.5 m^2 (178 ft^2), aspect ratio of 7.3, and mean aerodynamic chord of 1.53 m (5.0 ft) were based on a projection of the outboard leading edge of the wing through the fuselage. The wing had a modified NACA 64_2A215 airfoil section with a geometric dihedral of 5° and a positive incidence of 2° with respect to the fuselage reference line. The wing had no twist and the wing-mounted engines had thrust lines parallel to the fuselage reference line. The horizontal tail was of the all-movable type (stabilator) with a travel of 3.4° to -12.8°. The stabilator had a trailing-edge tab which moved in the same direction as the tail with a deflection ratio (tab deflection/tail deflection) of 1.5. The travel of each aileron was from 15° trailing edge down to 18° trailing edge up.

The model was equipped with constant-chord, single-slotted flaps which had a normal travel of 0° to 27°. This was later changed for the wind-tunnel model to 0° to 33°. The flaps were modified with 20 slots (10 per flap) which were 5.08 cm (2.0 in.) in width and variable in length, depending upon rib spacing. The slots, which are shown in the photograph of figure 4, covered a total of 82 percent of the flap span and 14 percent of the flap chord. The slots were formed by injecting plastic foam into the flap around wooden plugs formed in the desired shape of the slot. The plugs were then removed and cut into slices so that they could be placed back into the slots to form the desired slot width, as shown in figure 5. Plug slices were always added to the aft portion of the slot to keep the open portion as far forward as possible. In attempting to keep the slots as far forward in the flap as possible, the slots were designed so that the upward projection of the leading edge of the slot just intersected the trailing edge of the upper surface of the wing. At $\delta_f = 27^\circ$ the front edge of the slot was later found to be partially blocked by the trailing edge of the wing, as shown in figure 6. Consequently, the maximum flap deflection had to be increased to 33°, as mentioned previously, to allow the slots to pass air unimpeded.

TEST CONDITIONS

The tests were made to determine the effects of slot spoilers on the static longitudinal and lateral stability and control characteristics of the model. The three thrust coefficients used $(T_c' = 0.0, 0.20, \text{ and } 0.44)$ represent flight conditions of low power, climbout at 90 percent power, and take-off or wave-off, respectively. The Reynolds number based on a mean aerodynamic chord of 1.53 m (5.0 ft) was 2.96×10^6 for $T_c' = 0.0$ and 0.20, and 2.39×10^6 for $T_c' = 0.44$.

The model was tested over a range of angle of attack from -4° to 20° for slot openings of 0.0, 0.20, 1.14, and 3.30 percent m.a.c. at two flap deflections $\left(\delta_f = 27^{\circ}\text{ and }33^{\circ}\right)$. Tests were also performed over a sideslip range of $\pm 8^{\circ}$ for the condition $\delta_s = 3.30$ and $\delta_f = 27^{\circ}$. To determine the effects of asymmetric slot-spoiler opening, the slot spoilers were opened $\left(\text{for } \delta_f = 27^{\circ}\right)$ to 3.30 percent m.a.c. on the right wing and were closed on the left wing.

Except for the tail-free condition, the tail incidence was zero with respect to the fuselage reference line. Downwash at the tail was determined by a calibrated pitch-yaw tube with the tail removed for various slot-spoiler openings at $\alpha = 4^{\circ}$, 8°, and 12°. To determine the effects of thrust coefficient and slot spoilers on stick-free stability at $\delta_f = 27^{\circ}$, the tail was freed from its restraining cable and tested at $T_c' = 0.0$, 0.20, and 0.44 with $\delta_s = 0.0$ and at $T_c' = 0.44$ with $\delta_s = 3.30$.

PRESENTATION OF DATA

The data from these tests have been corrected for airstream misalinement, mounting-strut tares, and jet-boundary effects.

The data are presented in the following figures:

RESULTS AND DISCUSSIONS

Longitudinal Effects

The effects on the longitudinal characteristics of opening slot spoilers are shown in figure 7 for two flap deflections and two thrust coefficients. These data are replotted in figure 8 to illustrate more directly the effects of slot opening on the lift, drag, and pitching-moment characteristics. The effects of power and flap defection are illustrated

in figure 8(a). The maximum reduction in lift coefficient is seen to be about 0.32 for the condition $\delta_f = 33^\circ$ and $T_c' = 0.20$. The corresponding changes in drag coefficient and pitching-moment coefficient are seen to be about -0.013 and 0.046, respectively. The slot blockage that occurred at $\delta_f = 27^\circ$ appears to have a significant effect on the lift-spoiling ability of the slots only at slot openings of 0.20 and 1.14 percent m.a.c.

Figure 8(b) illustrates the effect of slot width on lift, drag, and pitching moment at $\delta_f = 33^\circ$ for several angles of attack. The variation of lift coefficient with δ_s is seen to be very nearly linear. Previous investigations with an engineless wing-body model in the Langley 300-MPH 7- by 10-foot tunnel indicated a very nonlinear variation of ΔC_L with δ_s (ref. 2). The difference in behavior of these two models may be due to the significant differences between the models in flap geometry, slot geometry, model size, and power-plant effects. The effect of increasing slot width on drag coefficient is seen to be, in general, a reduction in drag which is consistent with the reduction in lift as the slots are opened. The greatest effect on the drag is seen to occur at $\delta_s = 3.30$, with the amount of drag reduction due to slot opening increasing with increasing angle of attack. Note that at $\alpha = 6^\circ$ and 8°, an initial increase in drag occurs with opening slots. This may be due to the restricted flow through the small slot opening energizing rather than detaching the boundary layer over the flaps. The resulting redistribution of the lift and change in downwash angle at the tail could have caused the observed effect of increasing the total drag slightly while decreasing the total lift slightly.

The effectiveness of the slots in spoiling the flap-induced lift is shown in figure 9, where it is expressed as the ratio of the amount of decrease in lift coefficient obtainable from opening the slots to the total change in lift coefficient due to flap deflection. Figure 9(a) shows that the effect of reducing the flap angle from 33° to 27°, where the previously discussed slot blockage occurred, was to reduce significantly the effectiveness of the slots at slot widths of 0.20 and 1.14 percent m.a.c. The slot effectiveness at $\delta_s = 3.30$ was apparently not seriously reduced by the blockage. The addition of power appears to have only a very slight influence on the effectiveness of the slots, with the effectiveness being slightly greater for the lower power setting. The effect of angle of attack on slot effectiveness, illustrated in figure 9(b), appears to be an increase in effectiveness as α increases up to 6°. At $\alpha = 6^\circ$, the slots are capable of spoiling 62 percent of the flap lift when fully opened. At $\alpha = 2^\circ$, which is more representative of the approach angle of attack for this airplane, the maximum effectiveness of the slots is about 56 percent.

The effects on the longitudinal characteristics of opening slot spoilers with the tail free are shown in figure 10. Tail-free data are different from stick-free data only in the effect of control-system friction. The results of figures 7 and 10 were used to generate the data plotted in figure 11, which illustrates the effects on the model longitudinal stability of varying the slots and varying the power. Figure 11(a) illustrates the effects on

tail-fixed (or stick-fixed) stability and figure 11(b) shows the effects on tail-free stability. Note that opening the slots generally increased both the tail-free and tail-fixed stability, with the increase being slightly greater for the tail-free case. The addition of power at $\delta_s = 0$ had a destabilizing effect on the model.

Figure 12 illustrates the longitudinal aerodynamic effects of opening the slots with the tail off. Note that the pitching-moment change (nose up) with increasing slot width is slightly greater than for the tail-on case of figure 7(b). Thus, the effect of adding the tail is to reduce the nose-up pitching-moment increment due to slot deflection by adding a negative change as the slots are opened.

The results of downwash measurements made at the tail location (with the tail off) at $\delta_f = 27^\circ$ for angles of attack of 4° and 8°, various slot widths, and two thrust coefficients are shown in figure 13. The downwash angle can be seen to decrease, in general, as the slots open. This decrease would result in a negative pitching-moment change as the slots are opened, which is consistent with the difference between tail-on and tail-off pitching-moment changes noted previously. Note, however, that even with the tail on (fig. 7) the net pitching-moment change as the slots are opened is still nose up. The downwash data for $\delta_s = 0.20$ and 1.14 show no significant change from the $\delta_s = 0$ condition due to the slot blockage that occurred at these settings for $\delta_f = 27^\circ$.

Lateral Effects

The lateral characteristics of the model are shown in figures 14 and 15 for various slot widths and sideslip angles and a thrust coefficient of 0.44. No appreciable differences were found to exist in the lateral characteristics between the basic model and the model with symmetrically deployed slot spoilers.

A comparison of the lateral effects of an asymmetrical slot opening and a full aileron deflection are presented in figure 16. The full-left aileron deflection was left aileron 18° trailing edge up and right aileron 15° trailing edge down. The asymmetric slot condition was left-wing slots fully closed and right-wing slots fully open. The data show that for $\delta_f = 27^\circ$ and $T_c' = 0.44$, the roll-control power created by the asymmetric slot condition is about one-half the roll-control power available on the basic model. It should be noted that this rolling moment due to asymmetrical slot deflection could also be used to augment the roll capabilities of the basic model. Note that the diamond-shaped symbol represents the condition $\delta_a = 0^\circ$ and $\delta_s = 0$.

The effect of slot spoilers on the model lateral stability is shown in figure 17. The data, based on $\beta = \pm 8^\circ$, show that opening the slots has very little effect on lateral stability.

CONCLUSIONS

A wind-tunnel investigation has been conducted to determine the effects of slot spoilers on the longitudinal and lateral aerodynamic characteristics of a full-scale mockup of a light twin-engine airplane. The following conclusions were drawn from the results of the investigation:

1. Slots 5.08 cm (2.0 in.) wide, covering 82 percent of the flap span and 14 percent of the flap chord of a light twin-engine airplane with flaps deflected 33°, are capable of spoiling up to 62 percent of the flap-induced lift. This corresponds to a reduction in lift coefficient of about 0.32.

2. Opening the slots decreases the downwash angle at the tail.

3. The net change in pitching moment as the slots are opened is nose up. The magnitude of this moment is reduced by the negative contribution of the tail created by the decrease in downwash angle as the slots are opened.

4. Opening the slots has a slight stabilizing effect on both tail-fixed and tail-free stability.

5. Opening the slots symmetrically has no significant effect on the lateral stability of the model.

6. The roll-control power created by a fully asymmetric slot condition is about one-half the roll-control power available on the basic model for a flap deflection of 27° and a thrust coefficient of 0.44.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., June 18, 1973.

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3. Fink, Marvin P.; Shivers, James P.; Greer, H. Douglas; and Megrail, James L.: The Effects of Configuration Changes on the Aerodynamic Characteristics of a Full-Scale Mockup of a Light Twin-Engine Airplane. NASA TN D-6896, 1972.

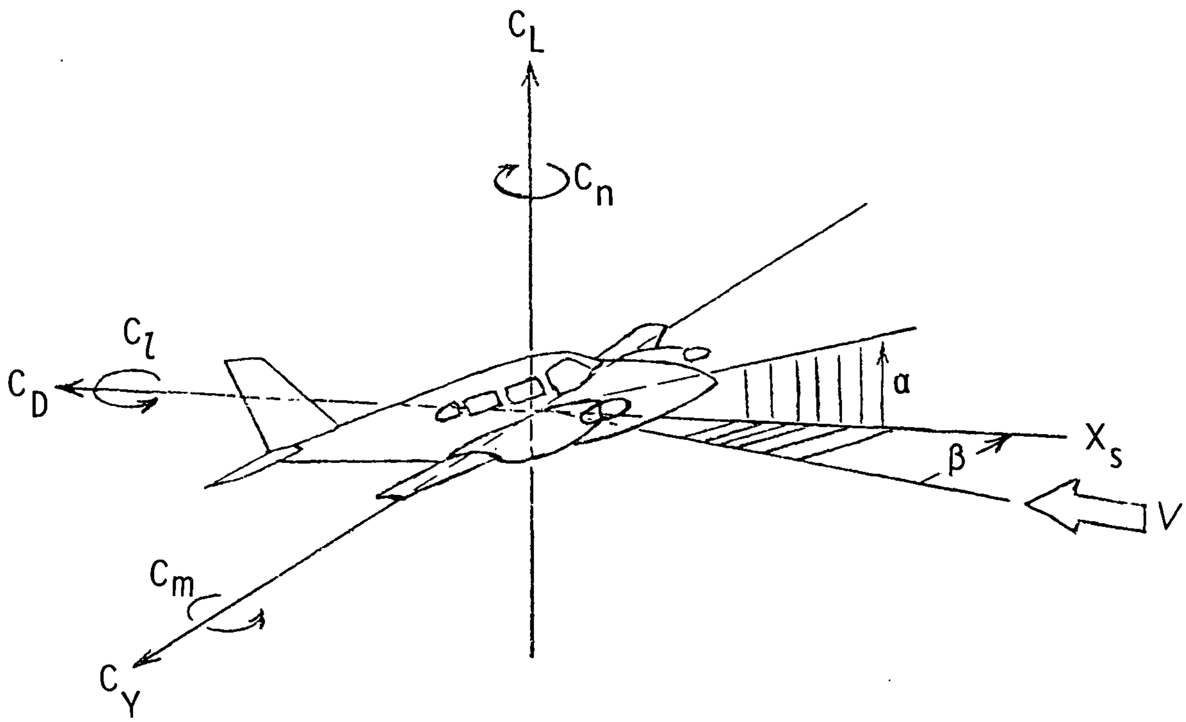

Figure 1.- System of axes and positive sense of angles, forces, and moments.

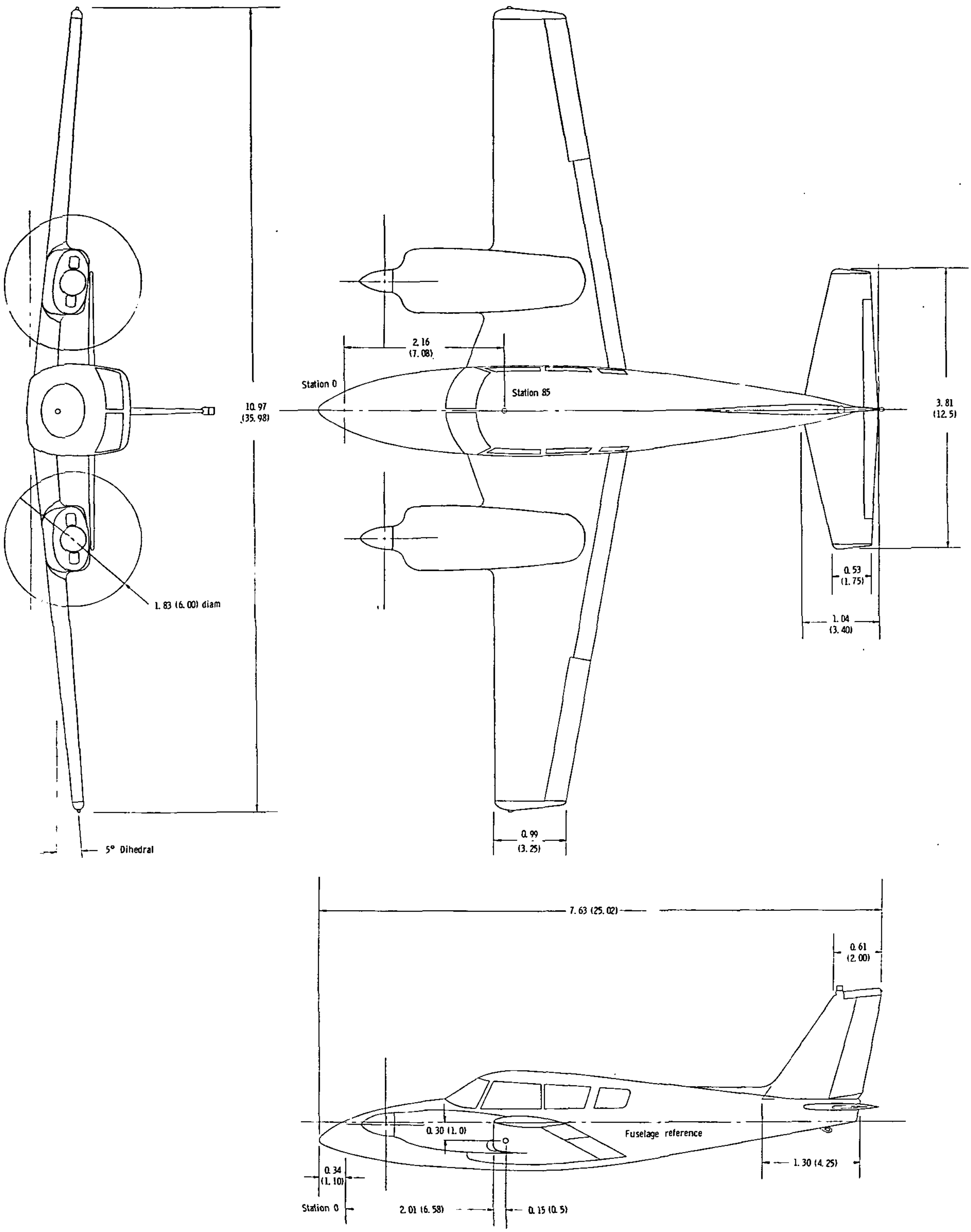

Figure 2.- Three-view drawing of model. All dimensions are in m (ft).

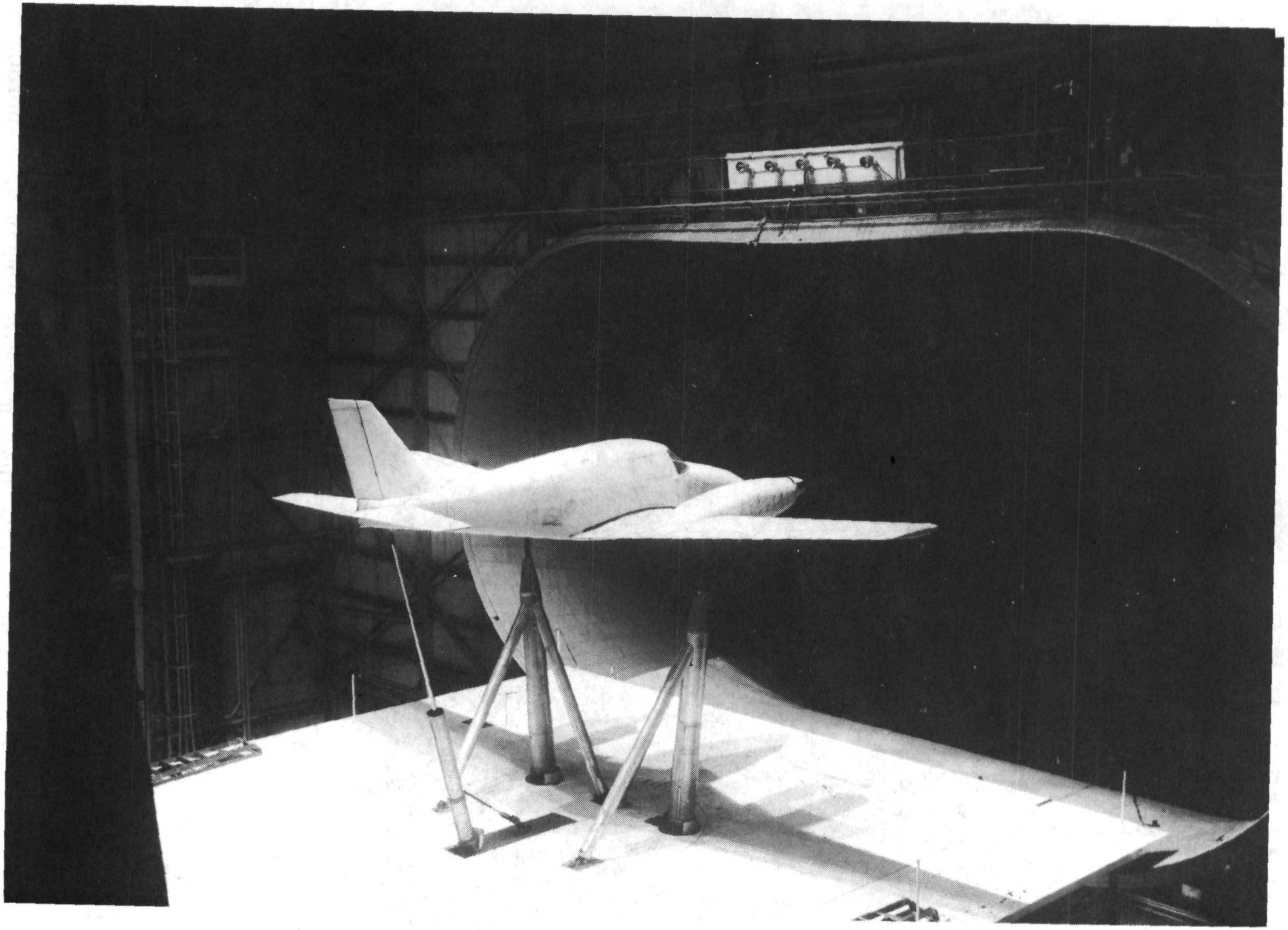

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Figure 3.- Model mounted in Langley full-scale tunnel.

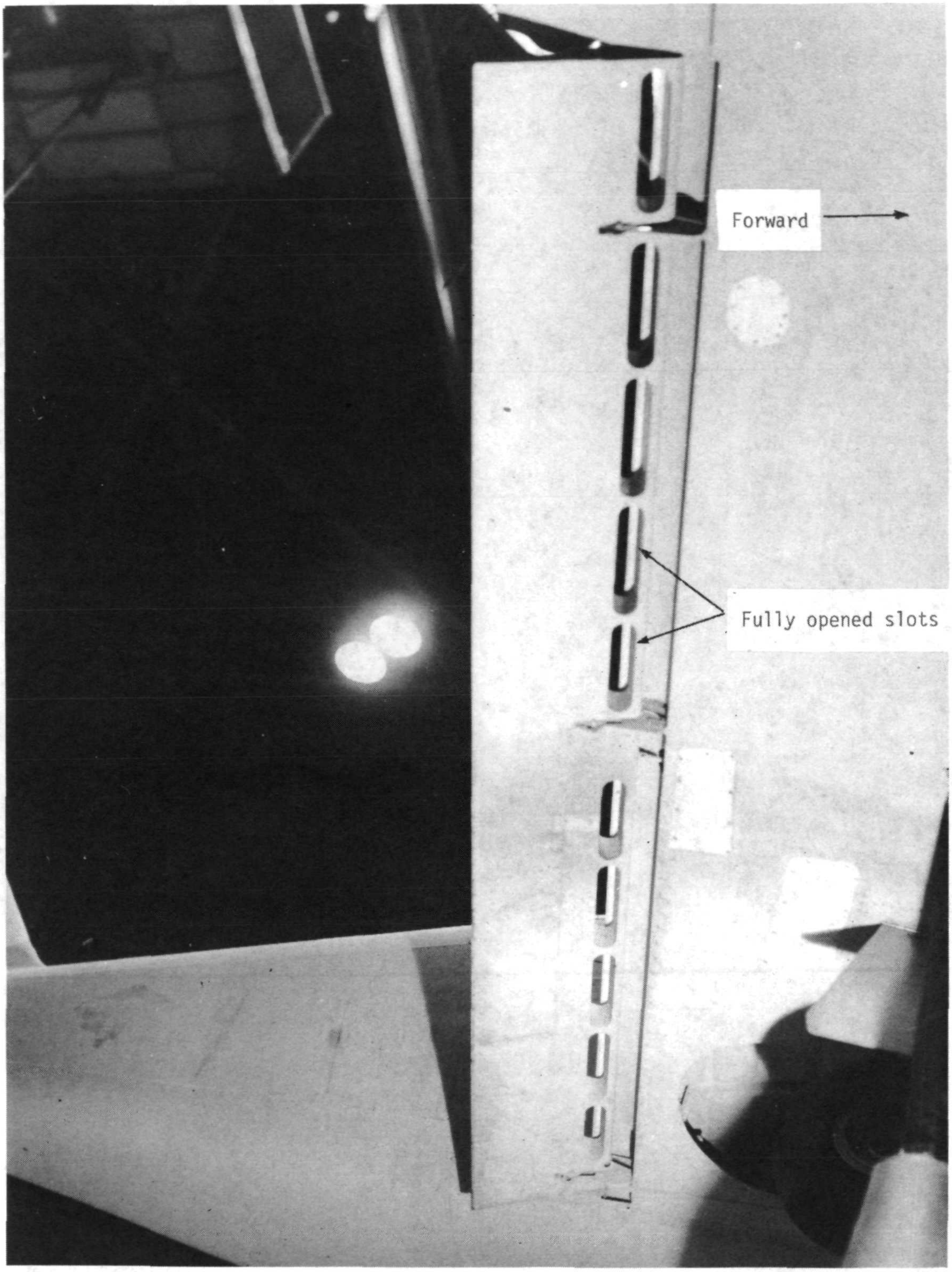

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Figure 4.- Starboard modified flap (looking upward from tunnel platform).

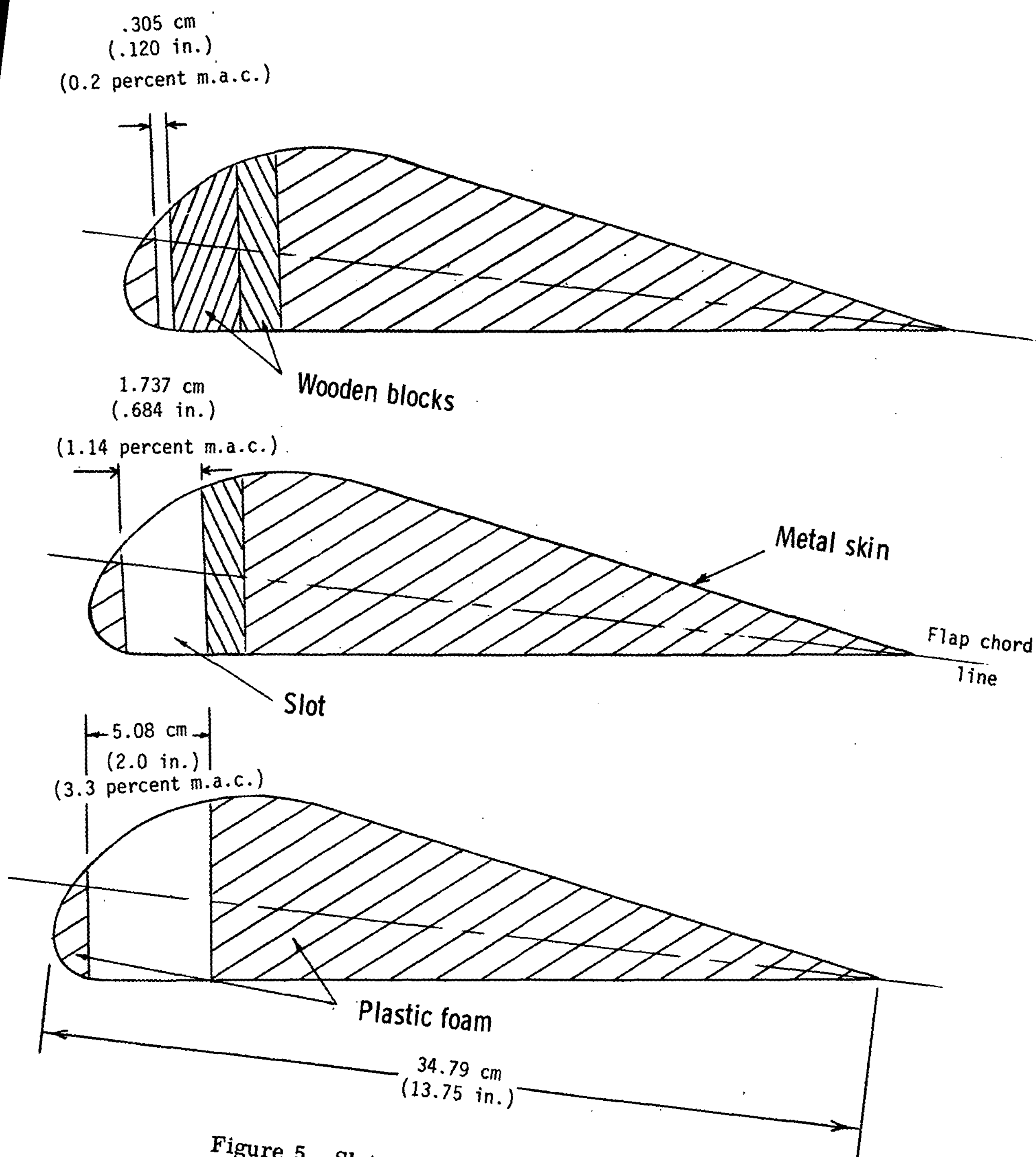


Figure 5.- Slot-width adjustment technique.

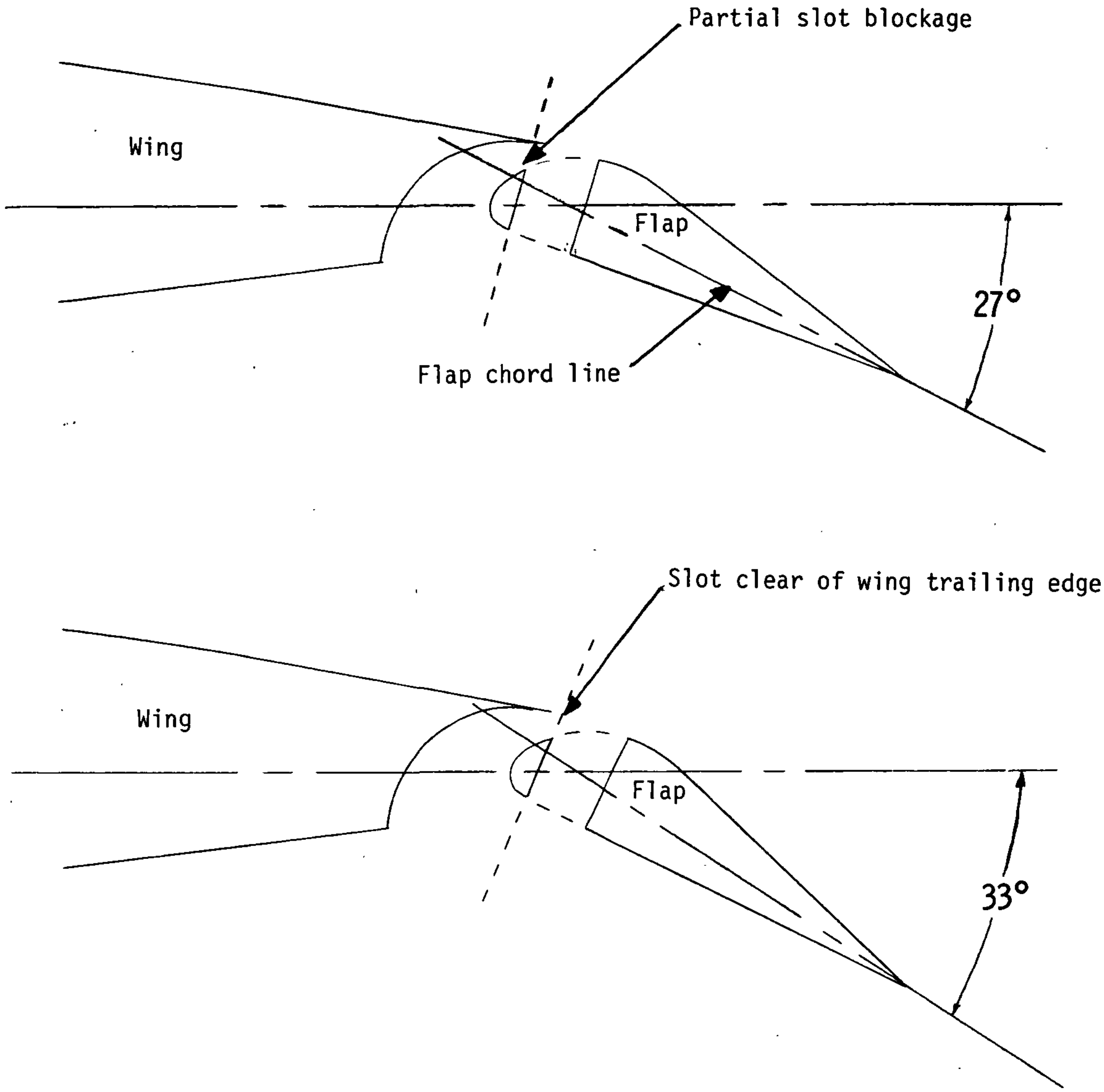
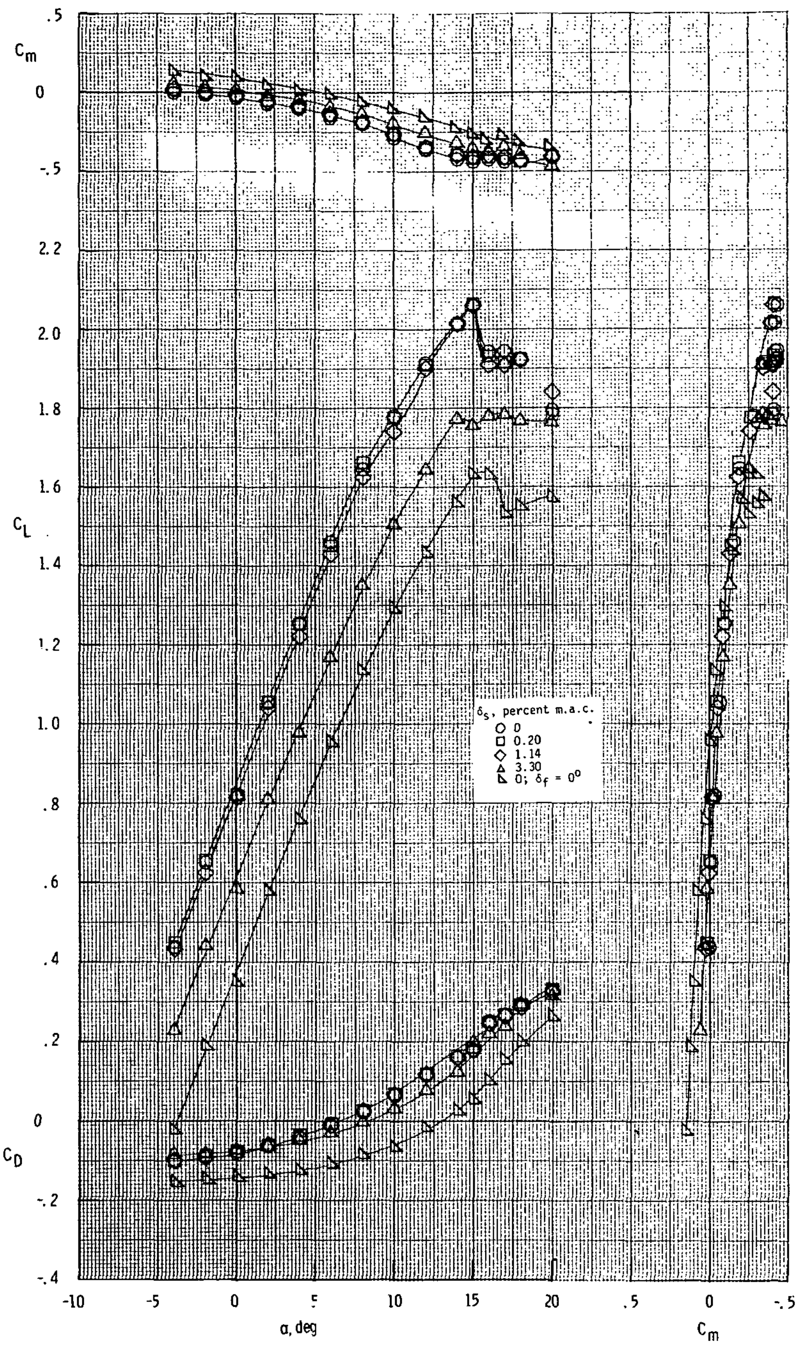
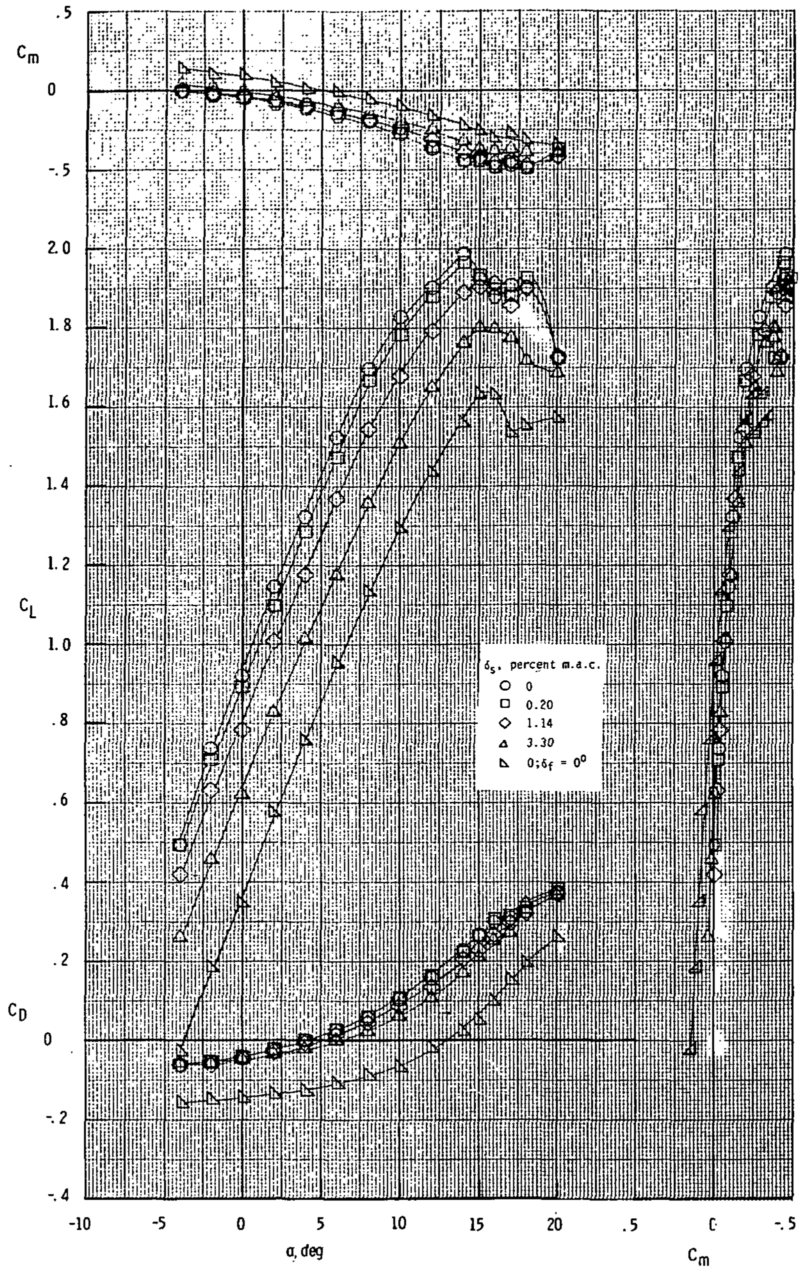


Figure 6.- Illustration of slot clearance at $\delta_f = 27^\circ$ and 33°.



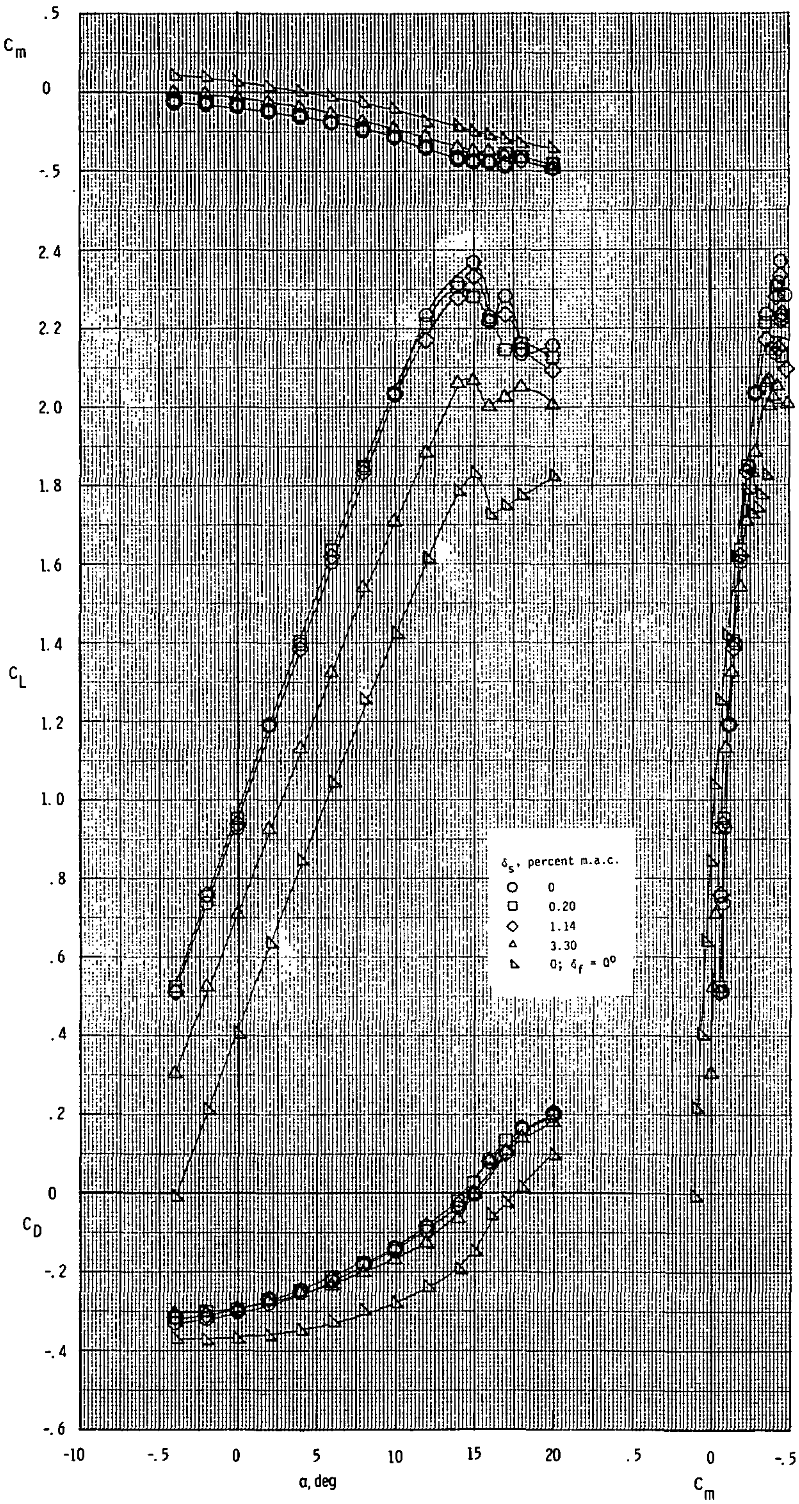
(a) $\delta_f = 33^o$; $T_c{}' = 0.20$.

Figure 7.- Longitudinal aerodynamic characteristics of the model for several flap deflections, thrust coefficients, and slot widths.



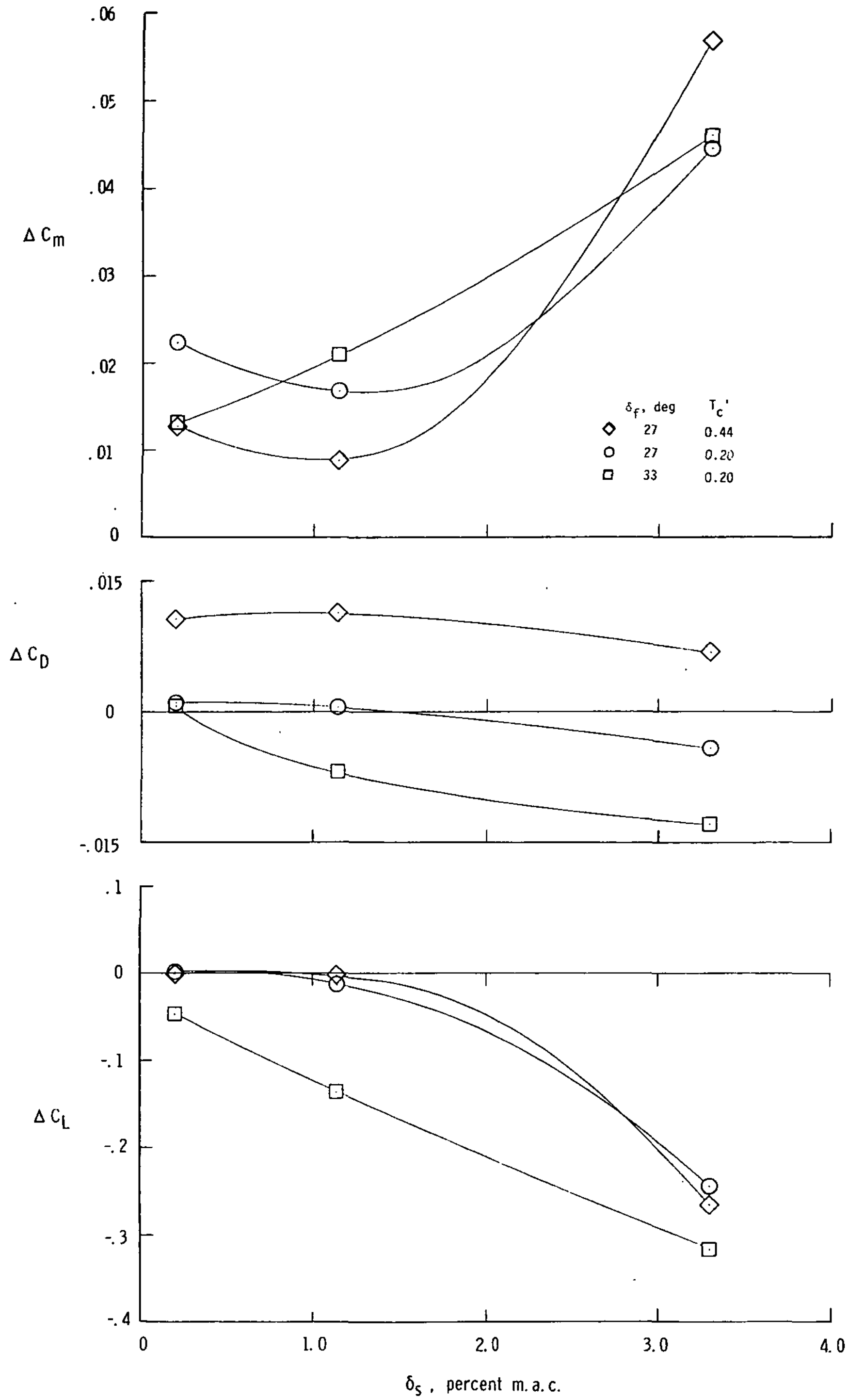
(b) $\delta_f = 27^o$; $T_c{}' = 0.20$.

Figure 7.- Continued.



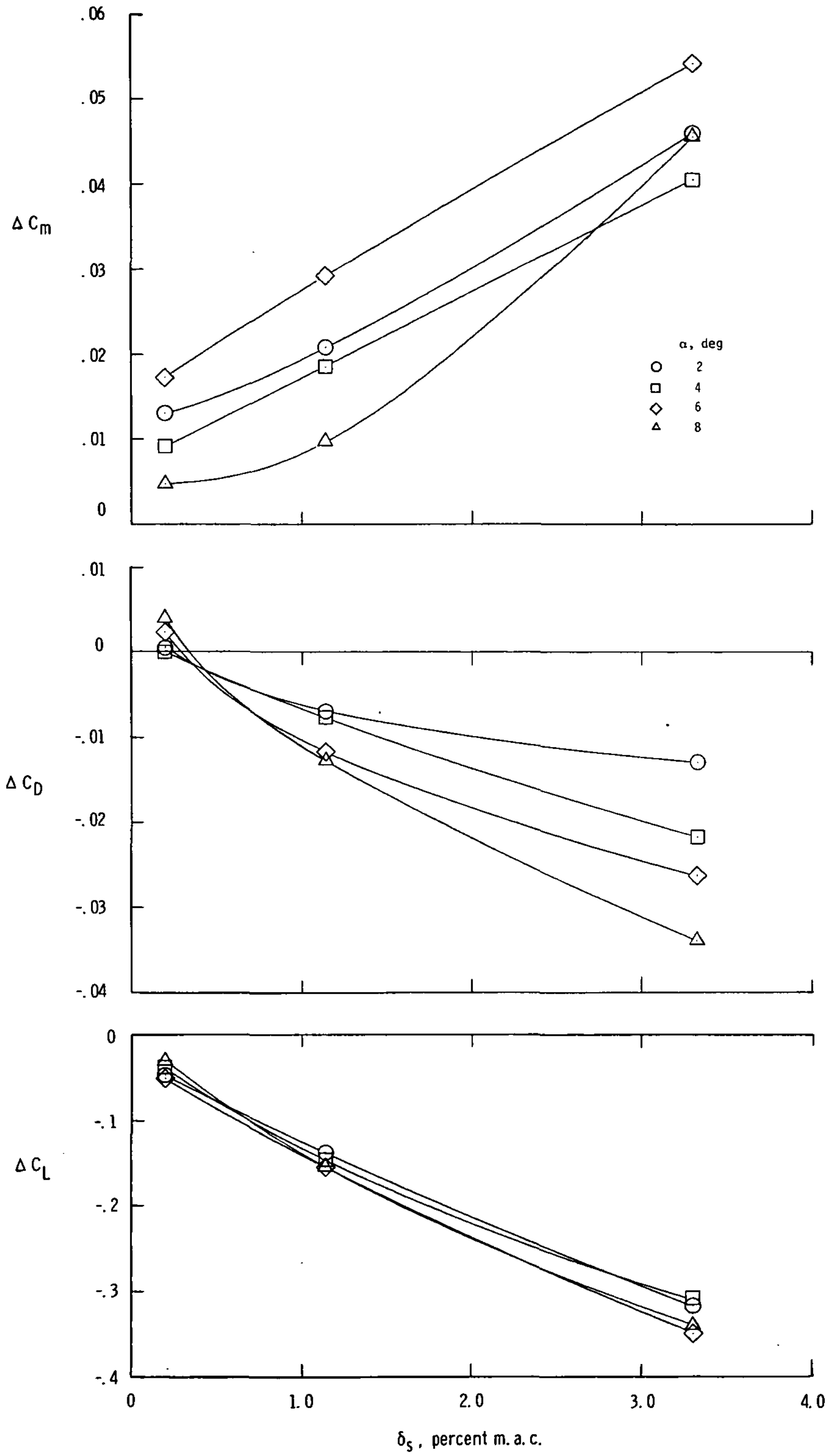
(c) $\delta_f = 27^o$; $T_c' = 0.44$.

Figure 7.- Concluded.



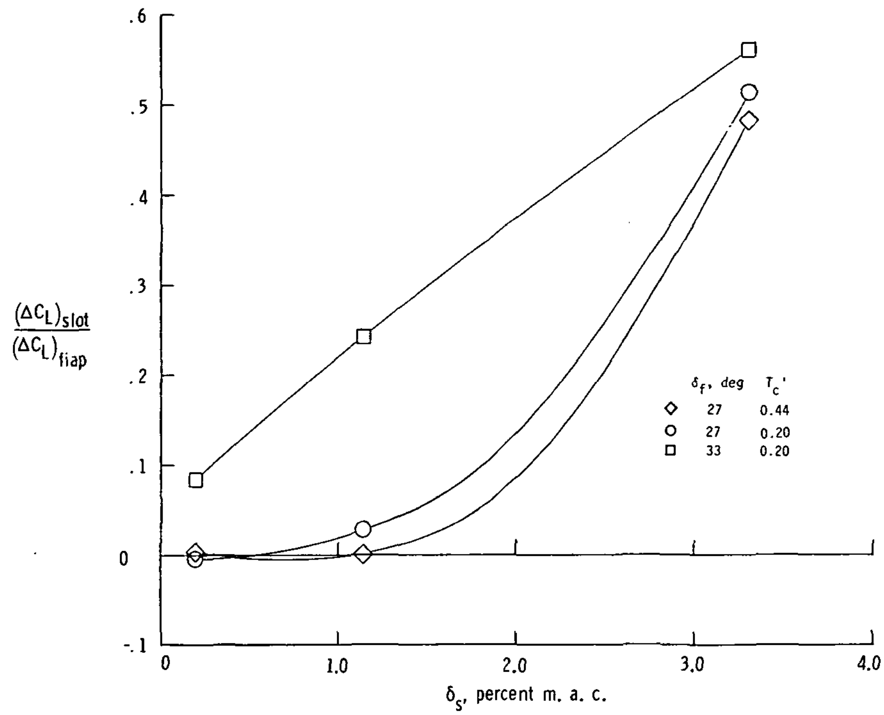
(a) Flap and power effects. $\alpha = 2^{\circ}$.

Figure 8.- Incremental longitudinal effects of slot opening.

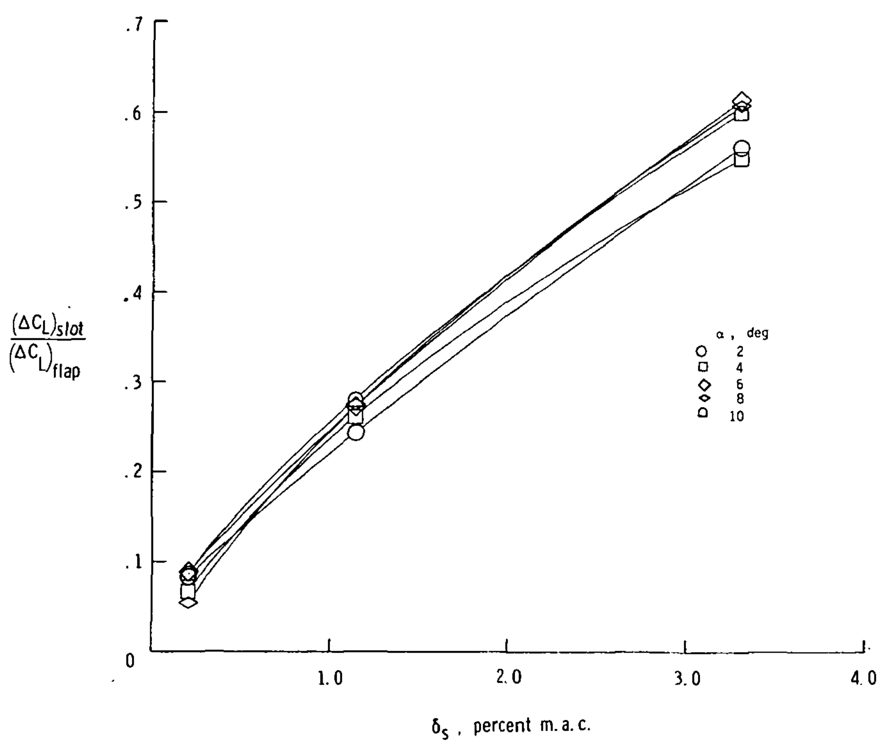


(b) Effect of angle of attack. $\delta_f = 33^o$; $T_c{}' = 0.20$.

Figure 8.- Concluded.

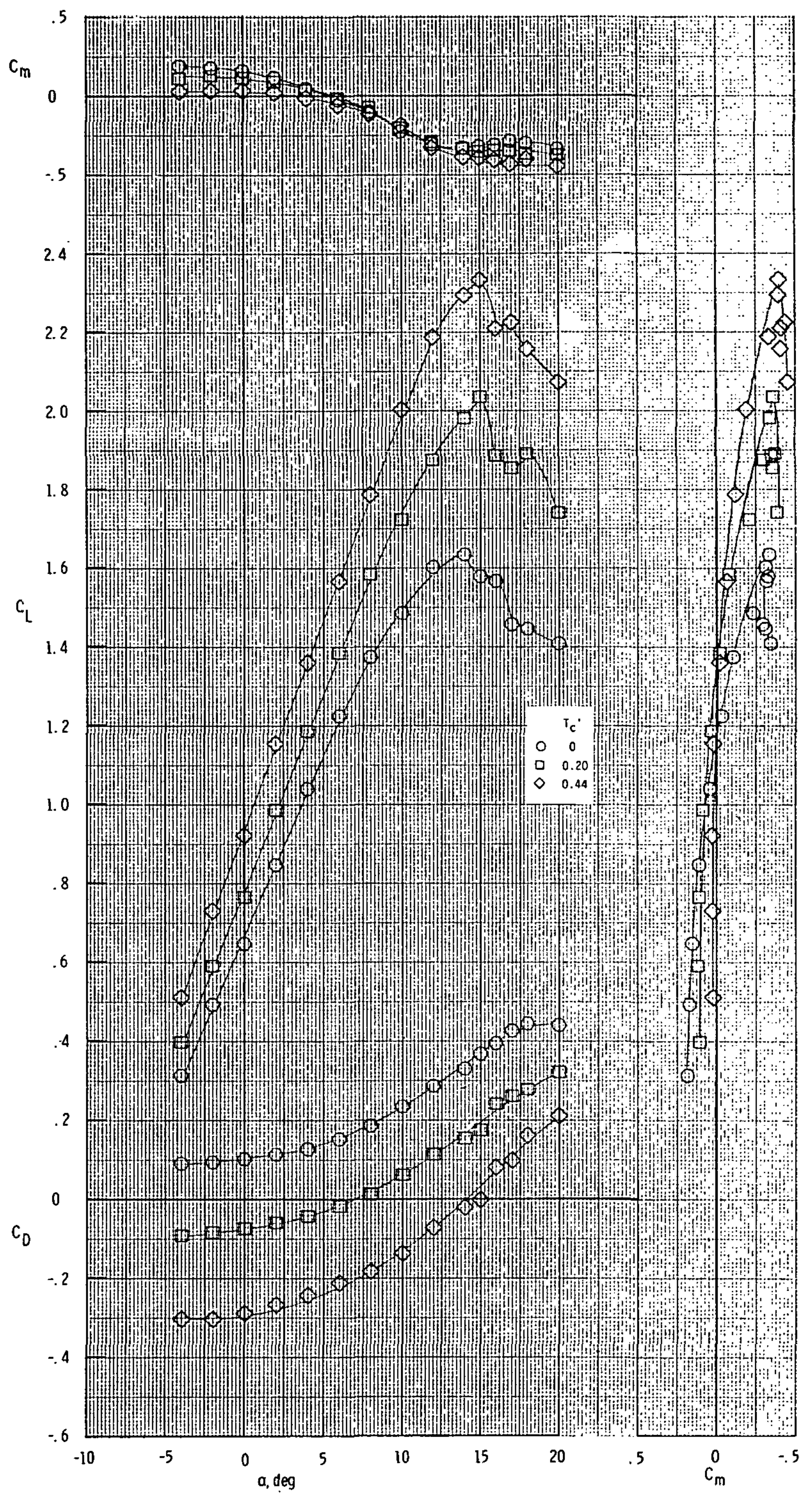


(a) Flap and power effects. $\alpha = 2^{\circ}$.



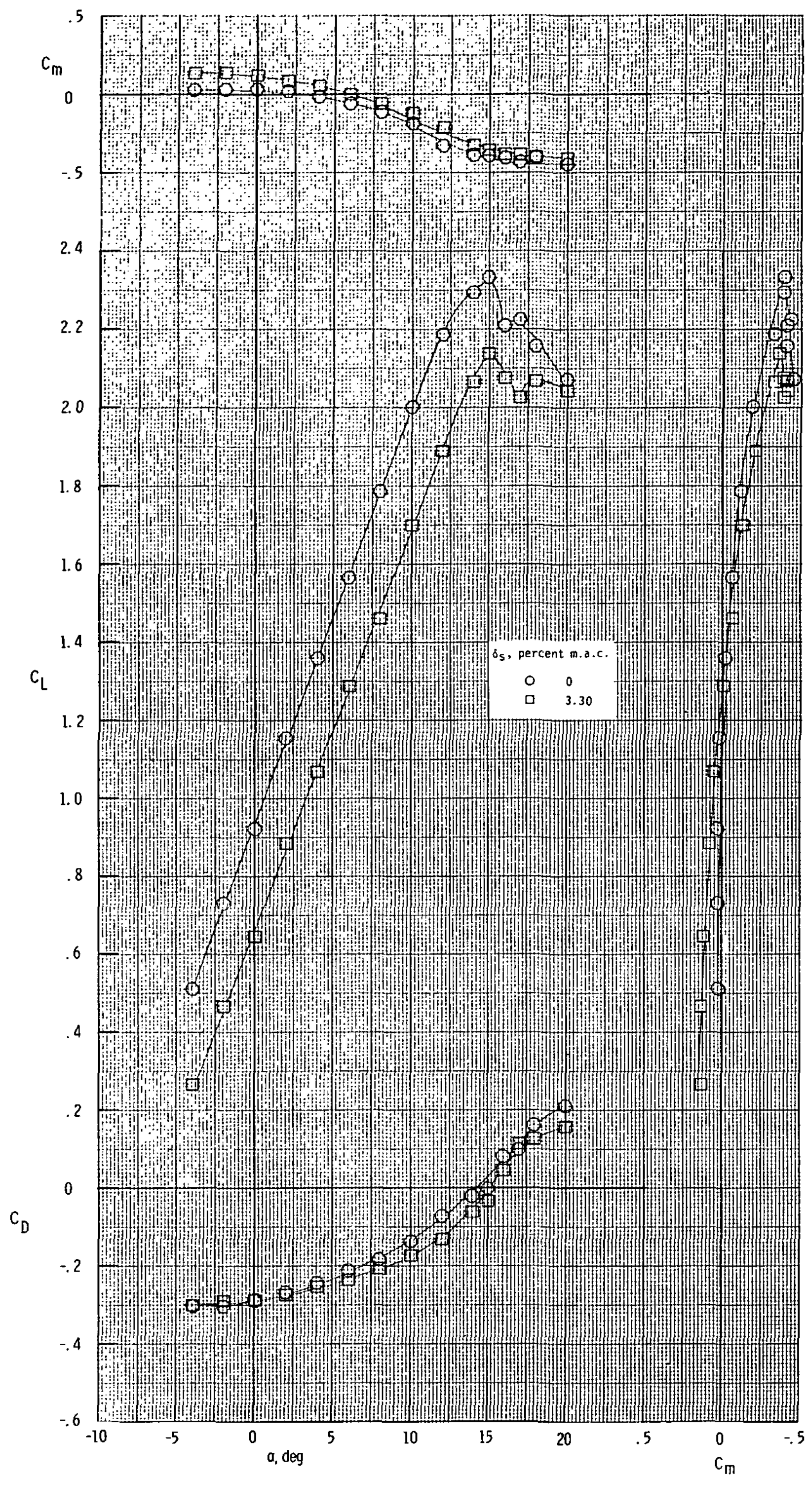
(b) Effect of angle of attack. $\delta_f = 33^{\circ}$; $T_c' = 0.20$.

Figure 9.- Slot effectiveness.



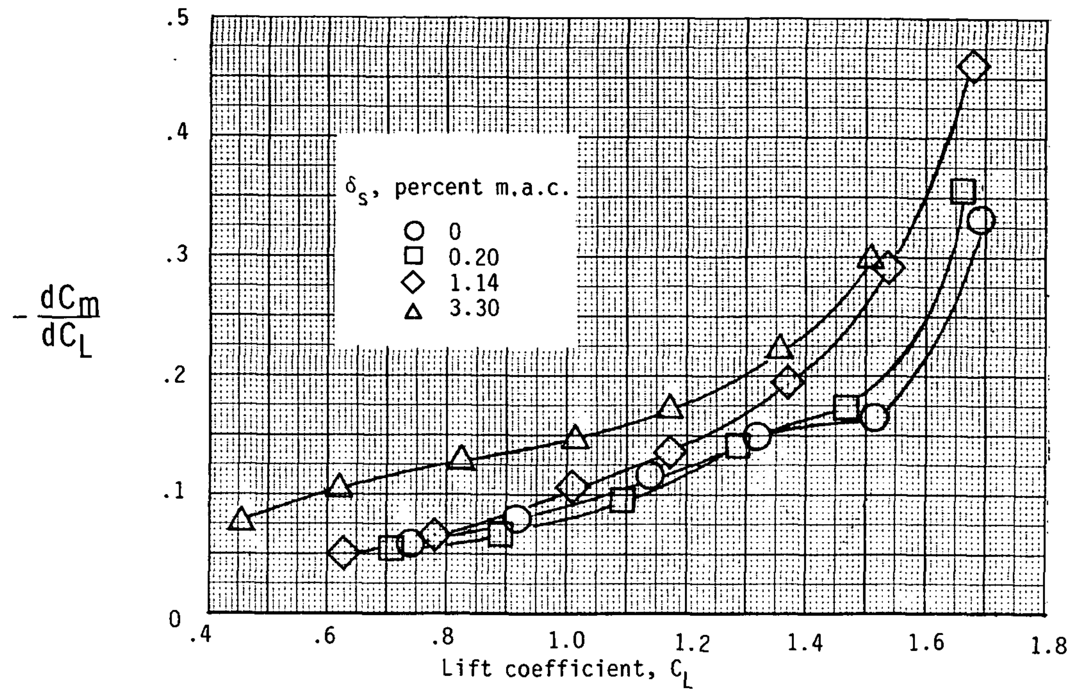
(a) Effect of power. $\delta_f = 27^{\circ}$; $\delta_s = 0$.

Figure 10.- Longitudinal aerodynamic characteristics of model with tail free.

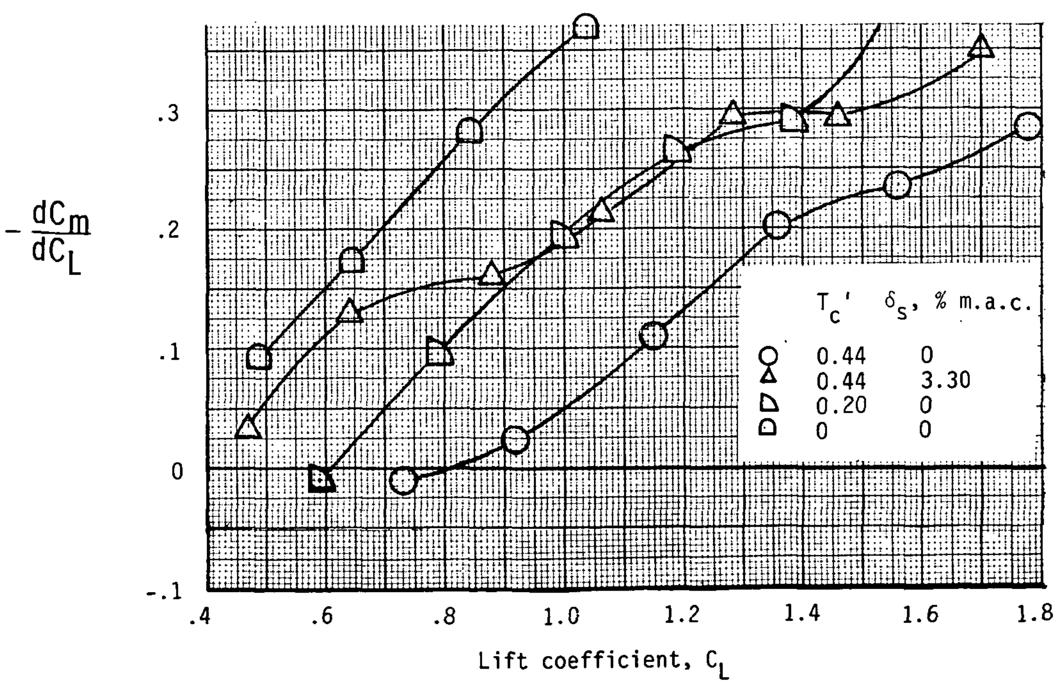


(b) Effect of slot opening. $\delta_f = 27^\circ$; $T_c' = 0.44$.

Figure 10.- Concluded.

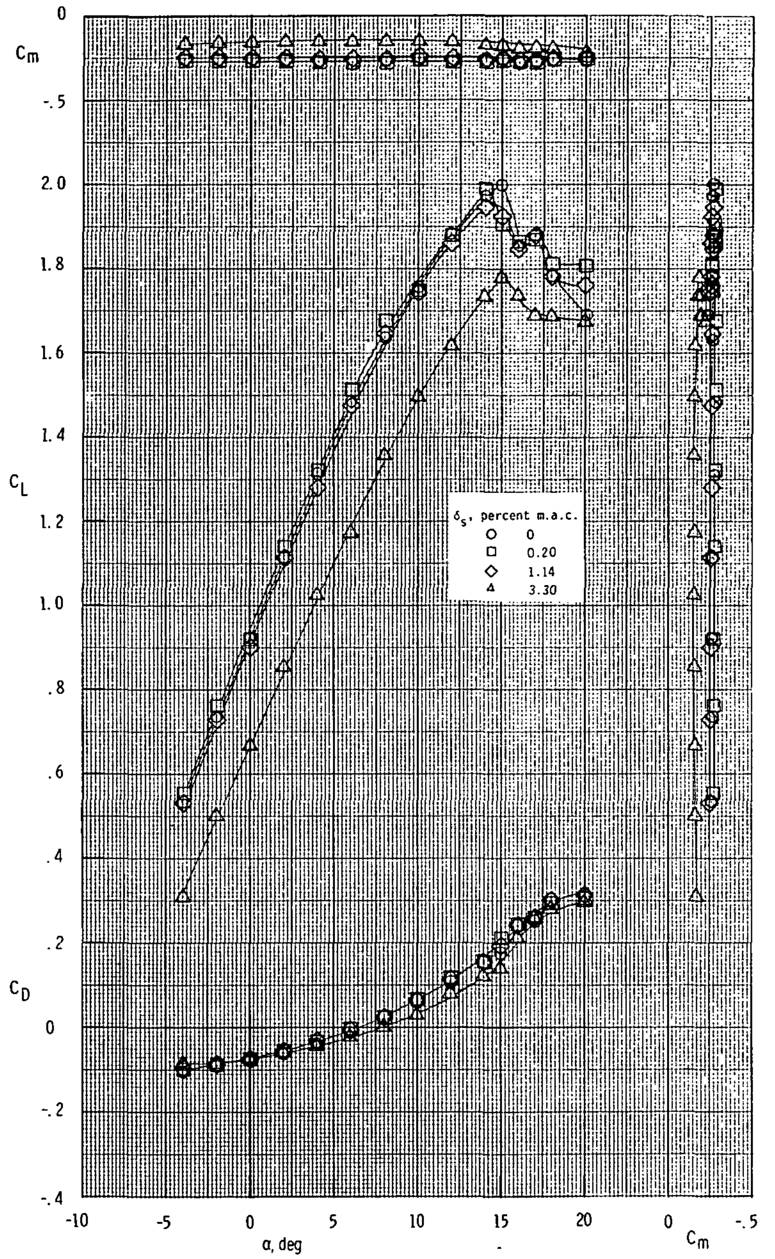


(a) Stick-fixed stability. $T_c' = 0.20$; $\delta_f = 33^{\circ}$.



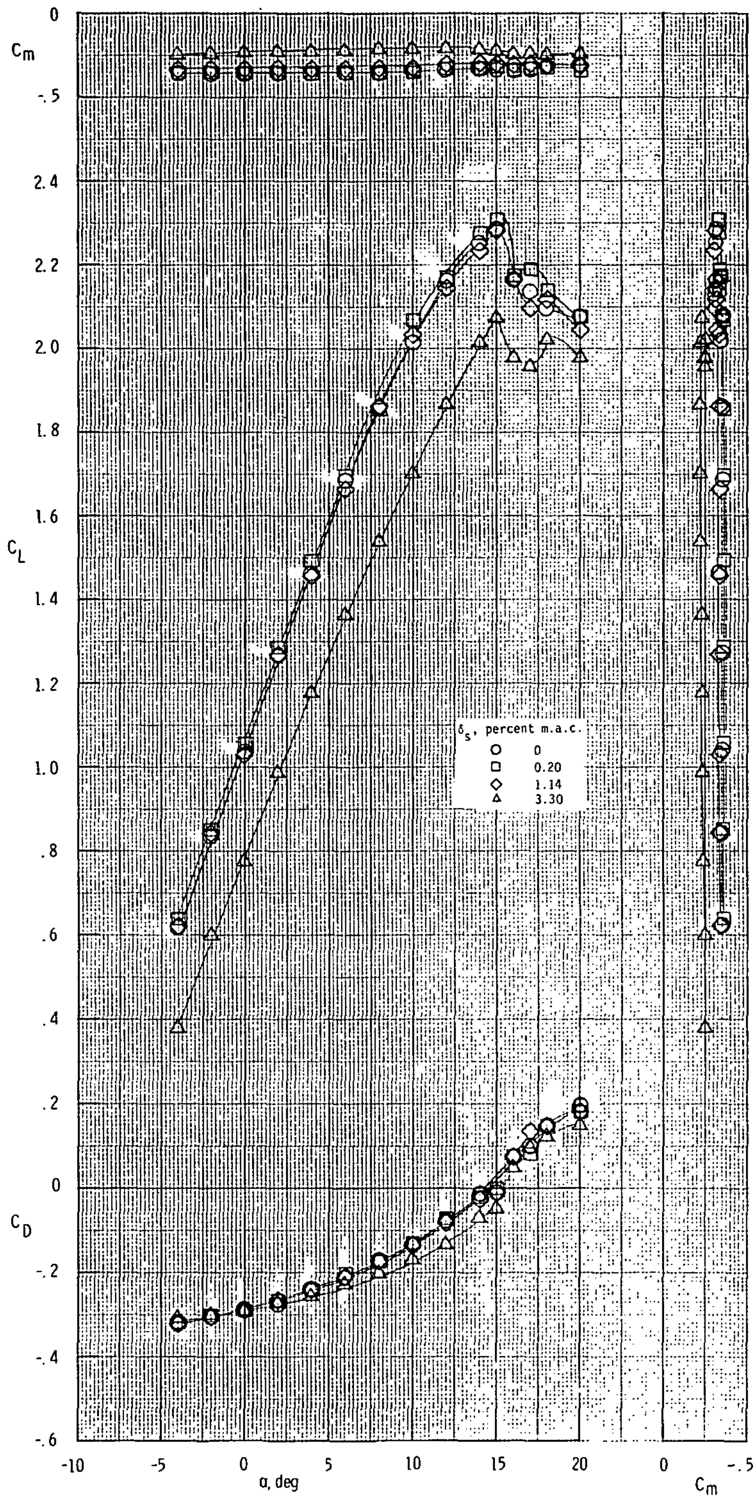
(b) Tail-free stability. $\delta_f = 27^{\circ}$.

Figure 11.- Effect of slots on longitudinal stability characteristics.



(a) $T_c' = 0.20$.

Figure 12.- Longitudinal aerodynamic characteristics of the model with tail off at two thrust coefficients for various slot openings. $\delta_f = 27^o$.



(b) $T_c{}' = 0.44$.

Figure 12.- Concluded.

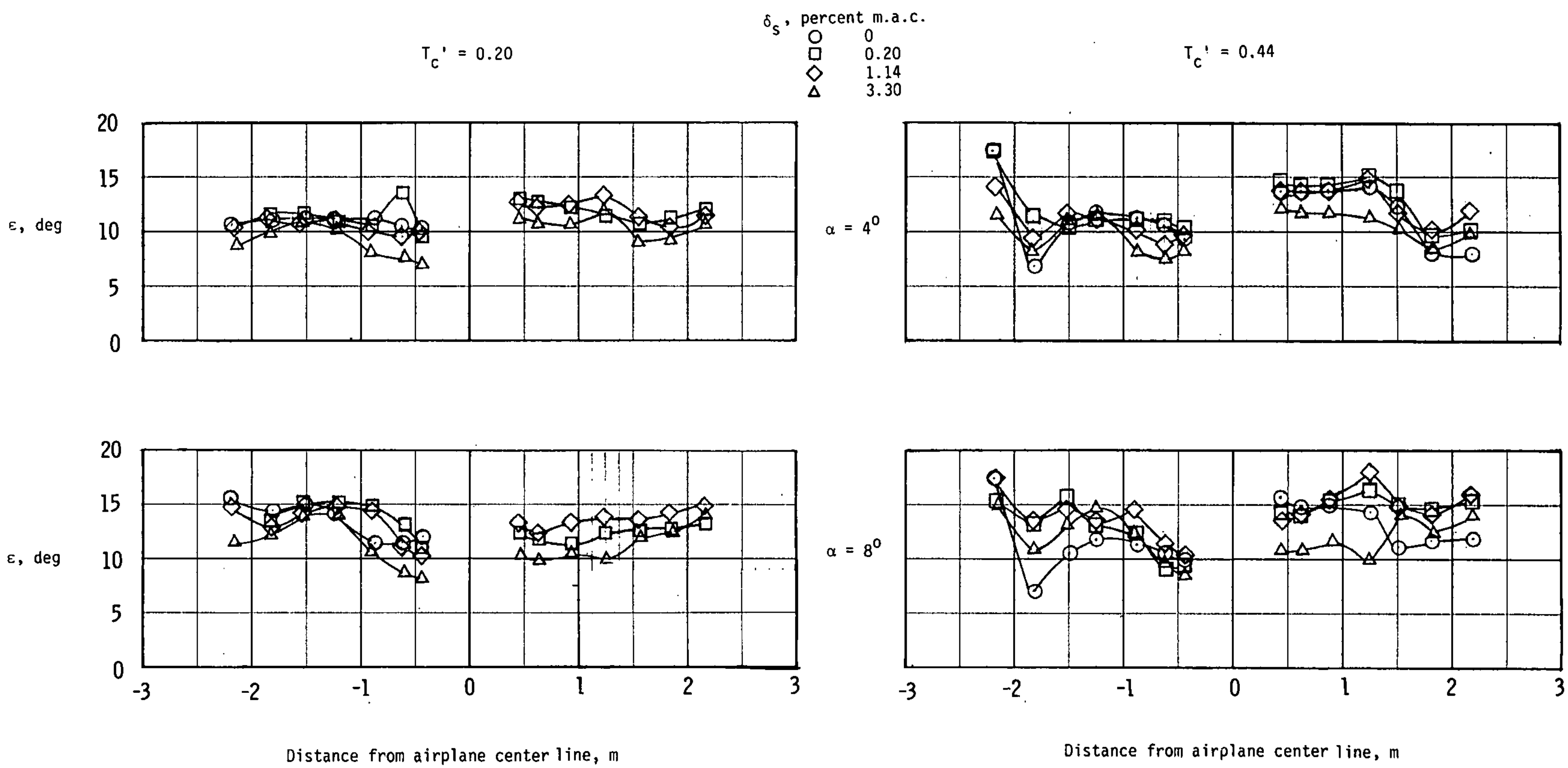


Figure 13.- Distribution of downwash across span of horizontal tail. $\delta_f = 27^{\circ}$.

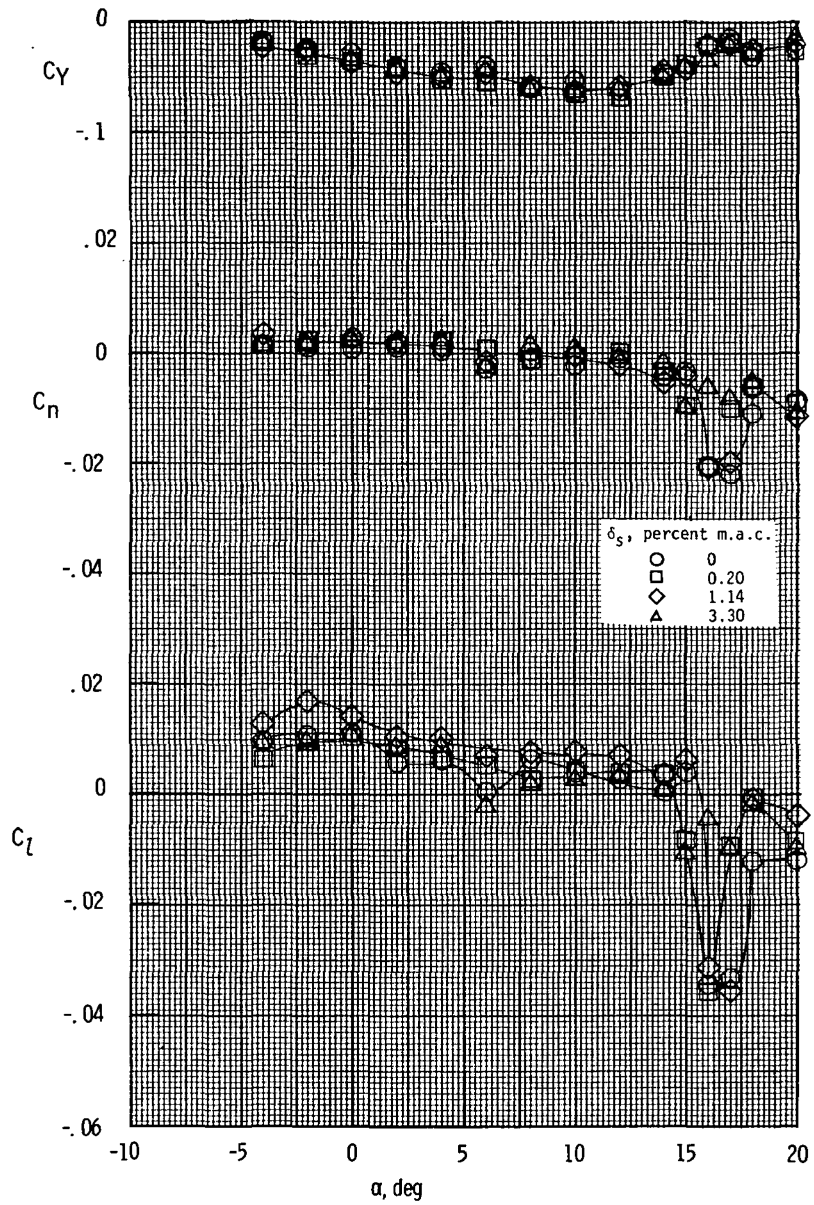
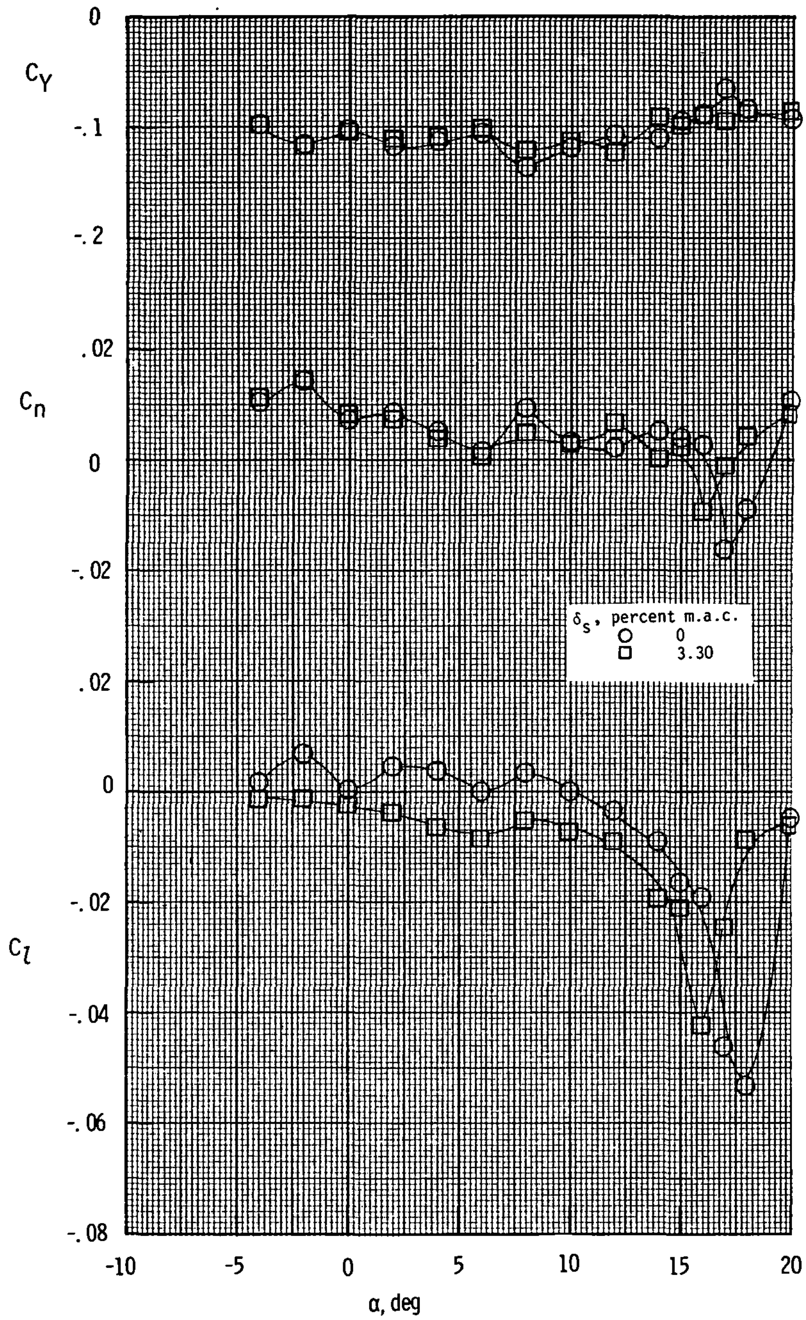
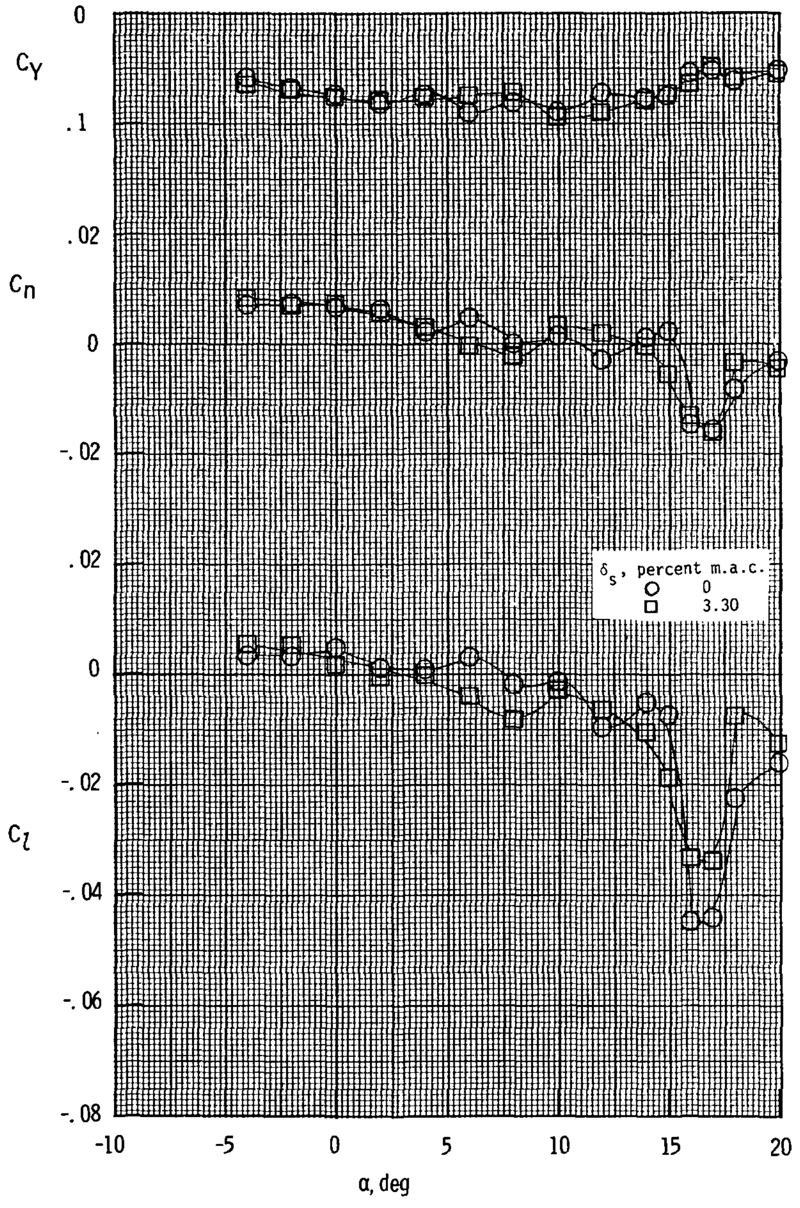


Figure 14.- Lateral characteristics of model for various slot openings. $T_c{}' = 0.44$; $\delta_f = 27^{\circ}$.



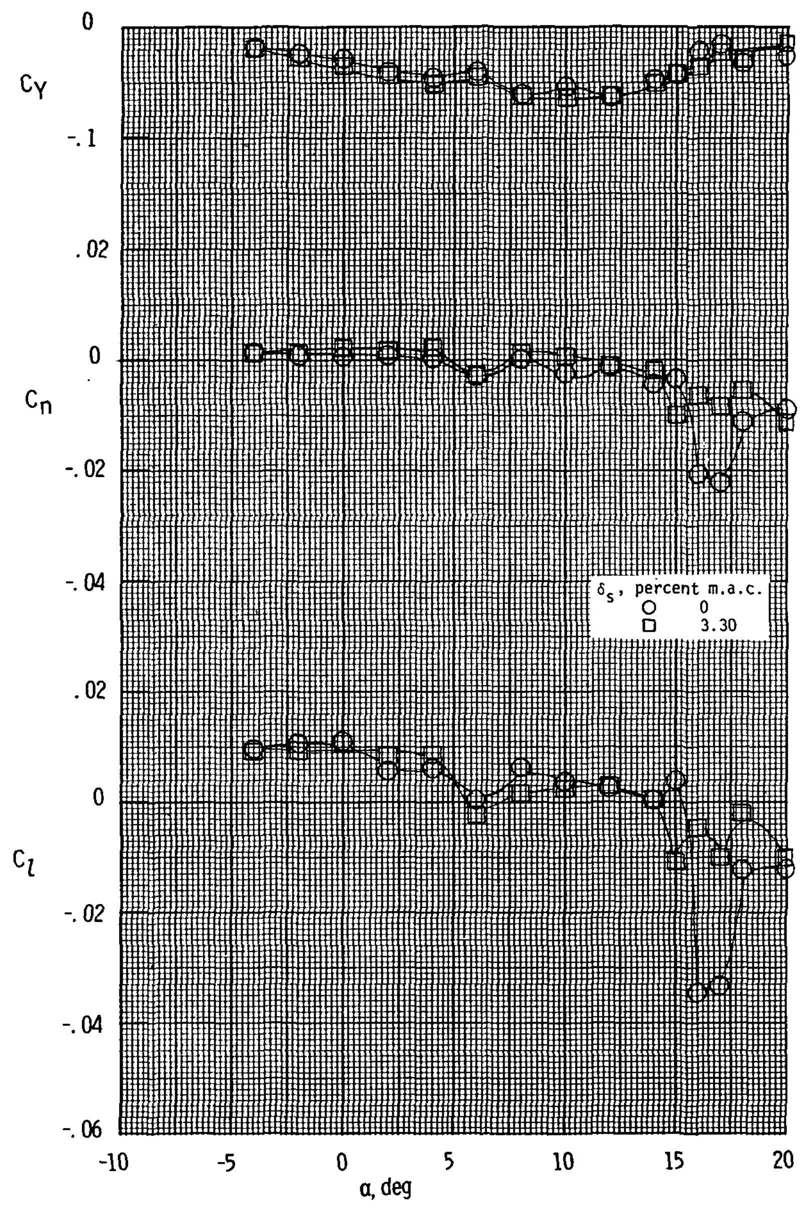
(a) $\beta = -8^{\circ}$.

Figure 15.- Lateral characteristics of model for various sideslip angles and slot openings. $T_c{}' = 0.44$; $\delta_f = 27^{\circ}$.



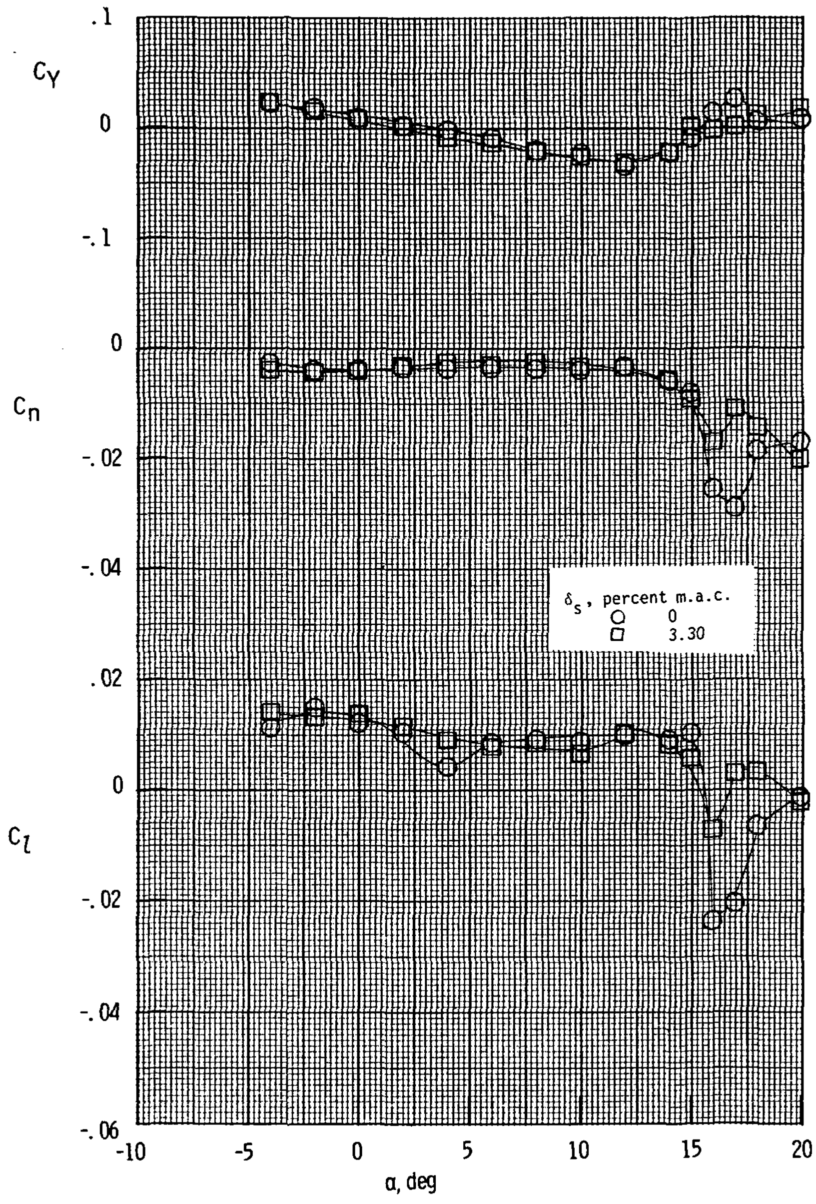
(b) $\beta = -4^{\circ}$.

Figure 15.- Continued.



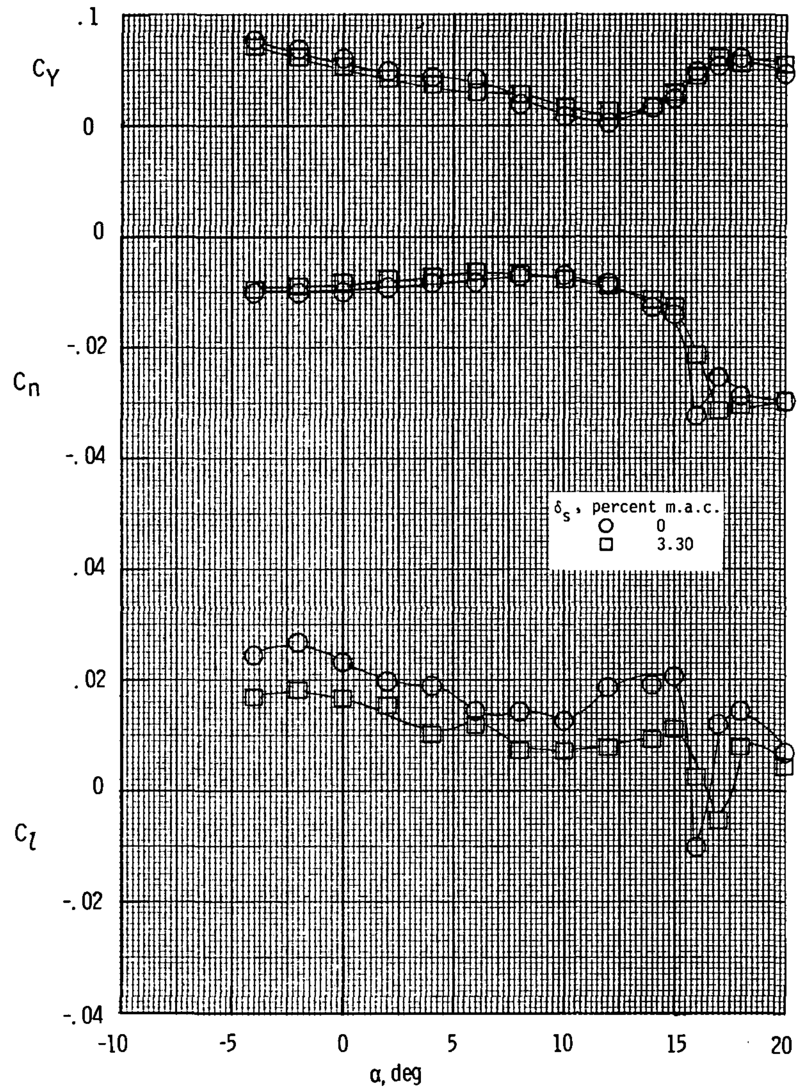
(c) $\beta = 0^{\circ}$.

Figure 15.- Continued.



(d) $\beta = 4^{\circ}$.

Figure 15.- Continued.



(e) $\beta = 8^{\circ}$.

Figure 15.- Concluded.

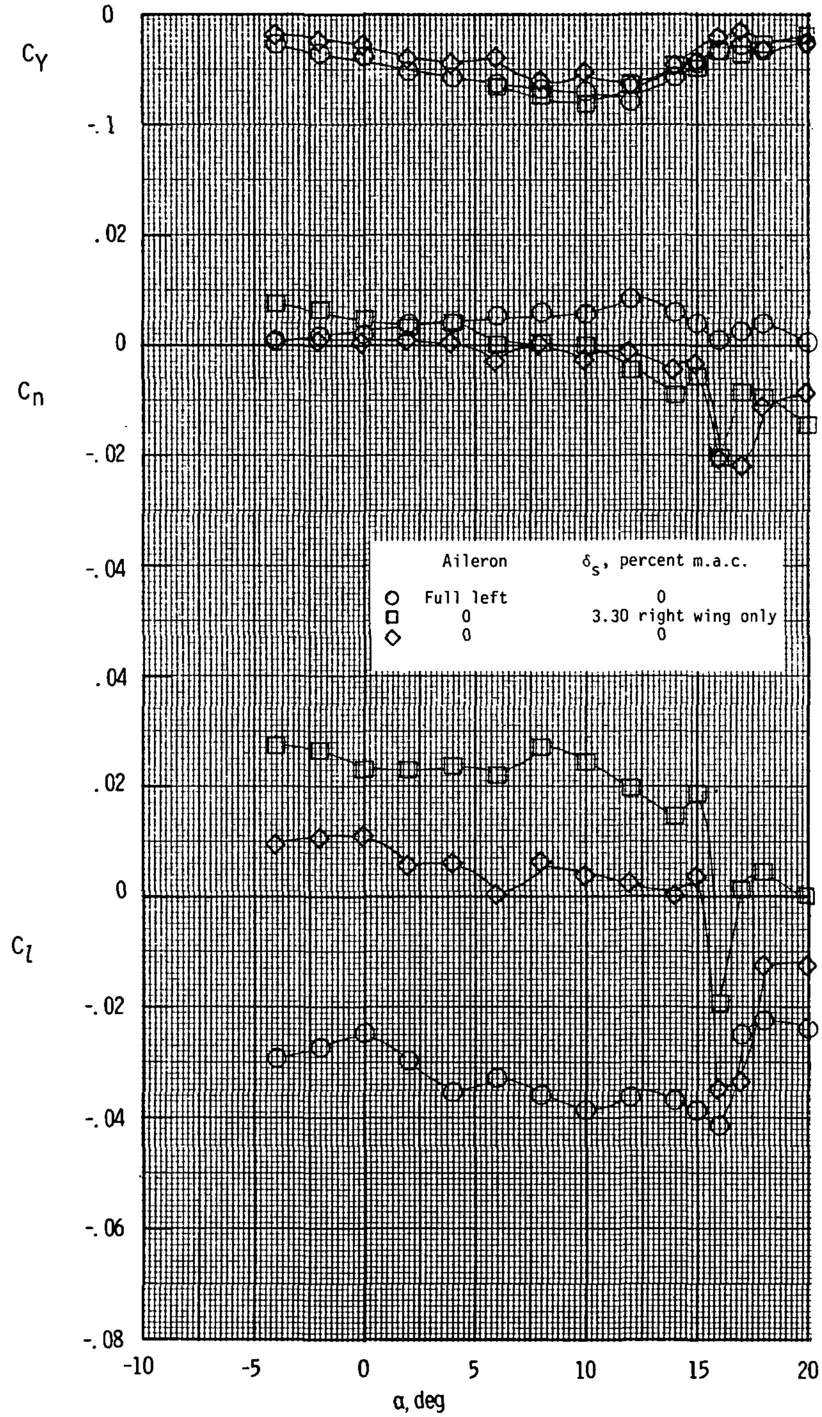


Figure 16.- Lateral characteristics of model for asymmetrical slot opening and aileron deflection. $\beta = 0^{\circ}$; $\delta_f = 27^{\circ}$; $T_c{}' = 0.44$.

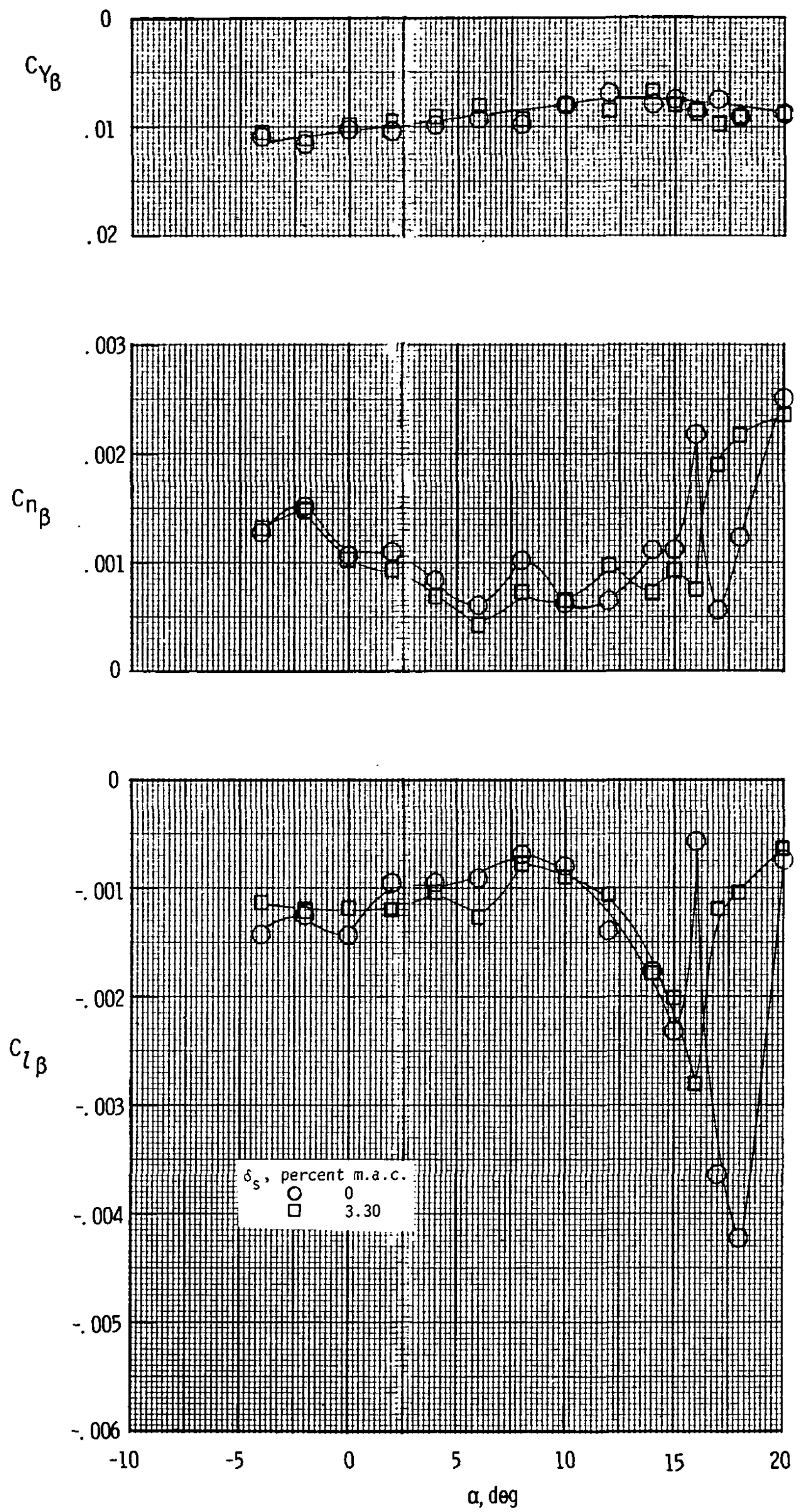


Figure 17.- Variation of lateral stability characteristics (based on $\beta = \pm 8^{\circ}$) for various slot openings. $T_c{}' = 0.44$; $\delta_f = 27^{\circ}$.

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